Comparative anatomy of Stomach

The stomach is basically a dilation of the digestive tract for the temporary storage of food. Only when its lining epithelium contains gastric glans, properly called a **true stomach**. The stomach is a muscular chamber or series of chambers that serve as a receiving site for recently ingested food, secrets digestive enzymes and lubricatory mucus, mixed with digestive juice. The digestive function of the stomach is apparently a secondary acquisition.

The shape of the stomach is related to the shape of the body. In such elongated creatures such as snake, it extends longitudinally, but in those with wider bodies it occupies a more transverse position. The end of the stomach, which connects to the oesophagous, is the **cardiac end**. The main portion is called the **body**. The pyloric end connects to the intestine and terminates at the **pylorus** or **pyloric valve**. This consists of a fold of the lining mucus membrane surrounded by a thick, involuntary sphincter muscle which regulates the passage of the contents of the stomach into the intestine.

The stomach is straight when it first differentiates in embryos and remains straight throughout life in some lower vertebrates. Most often flexures develop, producing J-shaped or U-shaped stomach. As a result, the stomach may exhibit a concave border or lesser curvature and a convex border or greater curvature. The lesser curvature is actually ventral and greater curvature is dorsal. The expansion at the cardiac end of the stomach, formed by the greater curvature, is the sac like **fundus, which** contains gastric glands. Fundic glands are composed of four functionally cell types:

a) Mucous cells: secretes soluble mucus.
b) Chief cells: known as zymogen or peptic cells, secrete pepsinogen. On contact with the acid of the gastric juice, the pepsinogen is converted to pepsin, a proteolytic enzyme.
c) Parietal (oxyntic) cells: secrete hydrochloric acid and intrinsic factor. Intrinsic factor, a glycoprotein that is essential for the absorption of vitamin B_{12}.
d) Enteroendocrine cells: secrete gastrointestinal polypeptide hormone gastrin, is the principal effective agent for stimulating the secretion of HCl.

Stomach in Cyclostomes

Cyclostomes have no definitive stomach. The stomach is poorly developed and consists of little more than an almost gradual enlargement at the posterior end of the oesophagous.

Stomach in Fishes

Stomach is not demarcated externally from the oesophagous but can be distinguished by differences in the mucosal folds which are thin in oesophagous and become thicker and wavy in outline in the stomach. A considerable variety of stomach shapes may be observed.

In *Polypterus*, stomach appears as a blind pouch having a long posterior caecum due to the fusion of cardiac and pyloric limbs along lesser curvature.

Shark has an expanded hook or J-shaped stomach generally without a caecum. The pyloric end is smaller than the cardiac portion. *Laemargus* and *Scymus* are peculiar in having pyloric caeca.

The stomach of *Amia calva* is large and sacculate with a distinct posterior caecum.

In herbivorous fish *Tilapia nilotica* or *T. mossambica* there is well developed stomach for hydrolysis of the algal wall.

The stomach is large and sac like in all carnivorous fish, those are predatory in habit. *e.g*., *Notopterus notopterus*, *Wallago attu, Sperata aor*.

Stomach of *Lepisosteus* is an elongated tube which posteriorly hooks to the right d forward to its pyloric valve. *Lepisosteus* has mass of tubular pyloric caeca.

In *Tenualosa ilisha*, *Mugil parsia*, *Gudusia chapra*, the stomach is reduced in size, but is greatly thickened to become gizzard like trituration of food.

The stomach of *Acipenser* is of a simple tubular form, without a posterior caecum. In its course it makes a complete circle, curving to the left, then formed and across to the right below the oesophagus. The pyloric end has thick muscular walls forming a massive pyloric sphincter.

All the fishes do not possess a true stomach and is absent in a number of species. In cyprinidae, the anterior part of the intestine is swollen to form a sac behind the oesophagous. This structure serves for the storage of food and known as intestinal bulb as in *Labeo bata*, *L. rohita*, *Catla catla, Puntius sophore.* Gastric glands are not present in intestinal bulb. *Scomberesox*, *Xenentodon* predatory fish has no stomach. *Hippocampus*, plankton feeders also without a stomach.

Stomach in Amphibians

All amphibians stomach have a digestive function. Highest differentiation in stomach takes place among anurans. The stomach lies on the left side in the body cavity attached to the dorsal body wall by a mesentry called **mesogaster**. In frogs the cardiac end of the stomach is wide, there is no fundus and the pyloric end is short and narrow. Pyloric stomach is provided with gastric gland. The stomach is not distinguishable grossly form the oesophagous.

In some urodels like *Necturas*, has a spindle shaped long stomach. The cardiac and pyloric part has no well demarcation.

Stomach in Reptiles

No striking deviations are to be observed in the stomachs of reptiles. Snakes and lizards have long, spindle-shaped stomachs in correlation with their elongated and narrow body shape. There is a clear-cut line of demarcation between stomach and oesophagous.

In turtles and tortoises due to peculiar body shape, the stomach is tubular but greatly curved into ‘U’ shaped structure.

Crocodiles have the most specialized gastric organs. Part of the stomach is modified into a gizzard like muscular region. Organ endowed with an specially thick muscular that grinds food .The thin walled glandular region of the stomach lies in front of the gizzard where gastric juice are added.

Stomach in Birds

In accordance with the lack of teeth and the type of food eaten by birds, the stomach has been modified greatly for trituration. It has become differentiated into two regions: **Proventriculus**, which continuous with the oesophagous, has a glandular lining which secrets gastric juices; **Gizzard**, much modified and muscular organ, which represents the pyloric portion of the stomach. The glandular cells lining the gizzard secrete a tough, horny layer which in some case bears bumps or tubercles on its surface. These aid in the grinding process.

The gizzard is best developed in grain eating birds. It is less developed in insect eating birds. Gizzard is absent in necter eating bird.

Stomach in Mammals

Many modifications exist in the transversely arranged stomachs of mammals.

In monotremes, true stomach absent, epithelial lining lacks gastric glands, presence of pouch like structure which serves merely for the storage of food.

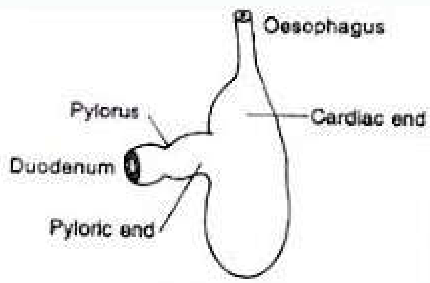

Fig. : Stomach of a monotreme

In platypus (*Ornithorhynchus*), stomach sis very simple, blind pouch like organ, has no clear distinction of parts.

Hindgut fermenters, members of Order-Perissodactyla (horse, ass, zebra, rhinoceros, tapirs) and elephants are the monogastric (= caecalid = hindgut) fermenters, have a simple stomach and an enormous caecum, a closed end sac at the junction of small and large intestines.

Foregut fermenters are examples of ruminant, in which the non-absorptive forestomach is divided into 3 chambers, which store food and process the food, followed by a 4th chamber in which digestion occurs. A **ruminant (=** *ruminare* = to chew over again) is a mammal of the Order-Artiodactyla that digests plant-based food by initially softening it within the animal's first stomach, principally through bacterial actions, then regurgitating the semi-digested mass, now known as **cud** and chewing it again. The process of rechewing the cud to further break down plant matter and stimulate digestion is called "**ruminating**". Ruminating mammals include cattle, goats, sheep, giraffes, bison, moose, elk, yaks, water buffalo, deer, camels, alpacas, llamas, antelope, pronghorn, and nilgai.

Ruminating stomach

Ruminating animals which chew their cud have the most complex stomach of all; *e.g.* in cows the stomach is 4 chambered:

1. Rumen (paunch)

Ruminants swallow partly chewed food into the first chamber, which is enormously enlarged. Here the food is moistened and churned, mixing with the symbiotic microorganisms that live in the rumen. The mucus membrane is provided with numerous short villi. Cellulase is produced from anaerobic bacteria that cleave the cellulose molecules into simpler carbohydrates.

2. Reticulum (honeycomb)

So named because the lining is honey combed by ridges and deep pits. The inner wall is lined with mucus membrane. Here the small masses (cuds) of moist plant materials are formed. These cuds are regurgitated when the animal is at rest, chewed again and swallowed into the rumen.

3. Omasum (psalterium)

Thoroughly masticated and finely ground cud is followed into the rumen and passes into the 3rd chamber-the omasum. The mucus membrane is raised up into numerous longitudinal leaf like folds.

4. Abomasum (rennet)

The abomasums has a smooth vascular and glandular mucus membrane. The food material passes through the abomasums where it is processed by the usual digestive enzymes. This portion is the **true glandular stomach** with gastric gland.

Mechanism of regurgitation

Rumination involves complicated waves of contraction that sweep through the rumen and that are synchronized with remastication and with passage of food along the digestive tract. Initially, ruminant animals clip plant materials, mix it with saliva, roll it into boli and swallow it into the rumen. Cycles of contraction pass through the rumen and reticulum to circulate and mix the ingested food with microorganisms.

Three steps are involved in regulation:

1. The ruminant contracts its diaphragm but keeps the glottis in closed condition. This produces a negative pressure in the thorax around the oesophagous.
2. The gastro-oesophageal sphincter is relaxed and the digesta are aspirated from the rumen into the oesophagous.
3. Peristaltic contraction sweeps the digesta up to the oesophagous into the mouth, so the animal can rechew the undigested plant material.

The process of regurgitation and remastication, termed **ruminating**, occurs repeatedly until most of the material is broken down mechanically. The amount of time on animal spends ruminating depends proportionately on the fiber content of the food. In grazing cattle, this may occupy up to 8 hour/day and involve rumination of each bolus 40-50 times.

In camel, the omasum is lacking. Beside this both reticulum and rumen bear pouch like diverticulae called **water cells**. Their openings are guarded by sphincter muscles. The function of water cells is to retain the metabolic water drawn from other parts of the body and is used to moisten the food during digestion, much comes indirectly from the breakdown of glycogen stored in the muscles and of fat stored in the hump.

The stomach of whales and hippopotamuses are divided into several compartments. In whale, the stomach is crop like structure of bird which is truly oesophageal derivative.

In Kangaroo, the pyloric portion has many peculiar sacculated folds in its wall.

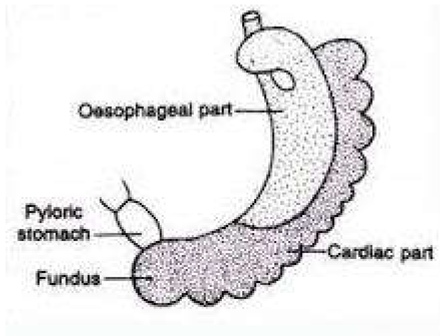

Fig. : Stomach of a Kangaroo (*Macropus*).

In vampire (blood-lapping) bat, *Desmodus*, the pyloric portion of the stomach is elongated into caecum like structure which fills with blood when the animal is engaged in feeding. Due to blood sucking habit, they have very short lumen in oesophagous and stomach through which solid food cannot pass.

In some monkeys, rodents a constriction marks off cardiac and pyloric regions, is referred to as a **bourglass stomach**.

Reference Books:

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"Honesty is very expensive gift"

Comparative account of Brain

The brain is the main part of central nervous system. It is the centre for all senses and muscular coordination. The brain is enclosed in the cranium and covered by membrane, called **meninges**. The meninges consists of 3 layers: Duramater (tough outer most layer), Arachnoid (middle portion) and Piamater (innermost layer contains blood vessel). Meninges act as protective function. In all vertebrates, the brain develops from the embryonic ectoderm. The early developmental pattern is very similar in all vertebrates.

Structure of a typical brain:

Typically in all vertebrates, the brain consists of 3 main divisions: **prosencephalon** or forebrain, **mesencephalon** or midbrain and **rhombencephalon** or hindbrain. The prosencephalon is further subdivided into an anterior telencephalon and a posterior diencephalon. The main part of the prosencephalon is **cerebrum**. Beside it, the prosencephalon consists of olfactory lobe, olfactory peduncles, pineal body, thalamus, hypothalamus etc. Mesencephalon remains undivided. It contains paired optic lobes. The rhombencephalon consists of metencephalon and myelencephalon. The metencephalon forms **cerebellum**, while the myelencephalon forms medulla oblongata which constitutes as the spinal cord.

The cavities of the brain are called ventricles. There are 4 ventricles present in the brain. The I and II ventricles (lateral ventricle) present in the cerebrum, III ventricle presents in diencephalon and IV ventricle presents inside both metencephalon and myelencephalon.

I and II ventricles connected to the III ventricle by separate **foramen of Monro**. III ventricle communicates with the IV ventricle by a narrow canal, called **iter** or **aqueduct of Sylvius**.

The cell body of neurons become segregated central part of the neural tube which persists in spinal cord region. In the brain region the cell bodies migrate toward the periphery. Thus, gray matter and white matters are differentiated.

Telencephalon

The cerebral hemisphere derived from telencephalon, *i.e.*, mainly associated with the intelligence, thought, reception and conduction of smell. At the anterior end of cerebral hemisphere is an outgrowth, which is known as olfactory lobe and subsequently associated with the posterior part of olfactory apparatus. The cerebral hemisphere enlarges to an increasing degree as the vertebrate scale is ascended.

The floor of the cerebral hemisphere is differentiated into **corpus striatum** *i.e.*, reticulated structure and the remainder part known as **pallium**. The pallium also becomes highly developed and modified in the evolution of the higher group of vertebrates.

Cyclostomes:

In cyclostomes each hemisphere is divided into an anterior olfactory bulb and a posterior olfactory lobe. It is concerned with receiving impulses from the olfactory apparatus and relaying them to the diencephalon.

Fishes:

In fish the telencephalon consists of a pair of solid olfactory lobes and two large cerebral hemispheres. The cerebral hemispheres are in the form of solid masses joined with each other in the midline and are covered with thin walled pallium, which is non-nervous. Olfactory lobes are conjoined to olfactory bulbs by olfactory nerve. The narrow space between thin roof and the solid hemisphere may be considered as 1^{st} and 2^{nd} brain ventricles. In elasmobranches and dipnoans the pallium is fairly thick. In fish telencephalon also acts as an olfactory centre.

Amphibia:

In amphibian two olfactory lobes form the anterior most part and emerge almost imperceptibly with the anterior end of cerebral hemisphere. The pallium is thicker than fishes and some cells from the gray matter have moved peripherally. The pallium is divided into two general regions: a dorsal, medial **archipallium** and a more lateral **paleopallium**. Both these structures are related to the olfactory sense.

Reptiles:

The cerebral hemispheres have increased in size and grown backward to cover partially the diencephalon and are separated medially by a deep fissure. The olfactory lobes are long and connected to the cerebral hemisphere by a narrow peduncle. In certain reptiles neopallium has appeared at the anterior dorsal end of each hemisphere between archipallium and paleopallium area.

In crocodilians, for the first time, nerve cells migrate into the neopallium and become arranged along its outer surface, forming a **true cerebral cortex**, which serves as an association centre.

Birds:

In birds, olfactory lobes are practically rudimentary. Archipallium and paleopallium are present but neopallium is lacking in most forms. So, there is no cerebral cortex. The cerebral hemispheres are large because the corpus striatum is of unusal size.

Mammals:

The cerebral hemisphere in case of mammals is very large as neopallilum has increased enormously pushing archipallium area medially and ventrally where it continues to serve as an olfactory centre. The paleopallium is pushed ventrolaterally where it becomes **pyriform lobe**. It acts also as olfactory lobe. Pyriform lobe is separated from the neopallium by rhinal fissure. The cerebral cortex is best developed in man where it is few mm in thick.

Archipallium is pushed by neopallium, moves, rolls on itself length wise and sinks largely below the surface, thus forming a long arching band known as **hippocampus**. Its name is suggested by its rolling appearance seen in cross section. Hippocampus is associated mainly with memory.

The basal nuclei are moderately well developed in the interior of the hemisphere as the corpus striatum is divided into amygdala (archiostriatum), globus pallidus (paleostriatum) and neostriatum (caudate nucleus, putamen).

The mammalian corpus striatum is less conspicuous. The surface of cerebral hemisphere becomes folded and convoluted so that ridges and depression appear. The ridges are called **gyri** and depressions are called **sulci**. Larger mammals have more convolution than smaller species.

Starting from marsupials a broad white mass, the **corpus callosum** which composed of modulated fibers connect two cerebral hemispheres.

Diencephalon (Thalamencephalon)

The sensory portion of the eye developed from diencephalon. It is a small structure which is entirely hidden by enlarged cerebral hemisphere. It is divisible into dorsal epithalamus, lateral thalamus and ventral hypothalamus. The epithelial lining of the dorsal roof plate covering the third ventricle (diocoel) together with the piameter forms **tela choroidea**. Vascular folds of telachoroidea extend into the third ventricle forming the **anterior choroid plexus**.

Posterior to the tela choroidea, the roof of the diencephalon consists of the epiphyseal apparatus. In several lower forms this is composed of **anterior parapineal** or **parietal body** and a posterior **pineal body** or **epiphysis**. Although both are present in lampreys, some fishes, frogs, *Sphenodon* and numerous lizards. Only the pineal body has persisted in most fishes, urodeles, many reptiles, birds and mammals. However, highest degree of development of parapineal body occurs in *Sphenodon*, forms a small **median eye**. It is developed to lesser degree in some lizards and **interparietal foramen** in the skull provides passage for the nerve connecting the median eye and the brain. In tadpole stage pineal body is connected to the pineal stalk but in adult frog it is separated from the pineal stalk and lies outside the skull below the skin at the **brow spot**. In case of lampreys, both parapineal and pineal organs are associated with eye like structure having retina lens.

In all vertebrates, the pineal body is present and glandular in nature. The gland has a connective capsule with septa extending inward. The parenchyma is made up of pinealocytes and glial cells. The pinealocytes secrete **melatonin** (derived from tryptophan), is involved in daily and seasonal photoperiodically induced rhythms, in sexual behavior and reproduction and in thermoregulation. Melatonin synthesis and secretion are increased during the dark period of the day and maintained at low level during the day light hours. Thus, it controls the light-dark cycle in environment.However, in the course of evolution there has been a change from a primitive photoreceptive type of organ to a secretory structure.

Epithalamus is a dorsal segment of the diencephalon. It includes the habenula and their interconnecting fibbers the habenular commisure, stria medullaris and pineal gland. The function of the epithalamus is to connect the limbic system to other parts of the brain.

The ventrolateral wall of **thalamus** consists of a large number of nuclei are important relay centre. Significant centre are the lateral medial geniculate bodies which relay optic and auditory impulses respectively. In reptiles and mammals, the walls are thickened inwardly to meet the center of the third ventricle by amass of gray matter known as **intermediate mass** or **soft commissure**. The thalamus plays an important role in regulating states of sleep and wakefulness.

The ventral portion of the diencephalon attains its maximum development in the form of **hypothalamus** and **infundibulum**. The hypothalamus contains nerve centre which integrate the functions of the peripheral autonomic system with those of other nerve tissues. The important releasing factors and release inhibiting factors of the hypothalamus affect the release of hormone by the anterior lobe of the pituitary gland via the hypophyseal portal system. Hypothalamus consists of:

- **Optic chiasma** where the optic nerves cross.
- **Tuber cinereum**, believed to be the parasympathetic center.
- A pair of **mammillary bodies** for integration of olfactory sense.
- **Infundibulum**, the distal portion that contributes to the posterior lobe of the pituitary gland.

Mesencephalon

The embryonic midbrain undergoes relative less change than other portion of the brain. The floor and sidewall of the mesencephalon composed of fibre tracts the **cerebral peduncles**, connecting forebrain and hindbrain. Actually, mesencephalon consists of dorsally placed optic tectum and the ventral tegmentum. Tectum is thick than tegmentum because of accumulation of gray matter.

In lower vertebrates, tectum is in the form of two well developed **optic lobes** or **corpora bigemina**, which serves as centers for the visual sense. Each optic lobe contains a large cavity, the **optic ventricle**. Two ventricles together forming the mesocoel.

In higher vertebrates, optic lobes are almost solid structure and only the narrow cerebral aqueduct passes through the center of the mesencephalon. A transverse fissure divides the optic lobes of into 4 prominences, the **corpora quadrigemina** (Tectum). The anterior part, **superior (anterior) colliculi** contains receptive centers for the visual sense and the posterior pair, the **inferior (posterior) colliculi** serves to integrate auditory impulses. The superior colliculi are less important as visual centers with the great development of the cerebral cortex.

The Optic lobes are more conspicuous features of the brains of lower vertebrates and birds. In mammals, the superior colliculi have become less important as visual centers with great development of the cerebral cortex.

Metencephalon

The **cerebellum** develops as a large dorsal outgrowth from the metencephalon. Its function is to coordinate the neuromuscular mechanism of the body. The ventral portion portion of metencephalon in lower vertebrates is composed of heavy fibre tracts which emerge with medulla oblongata.

In fish, cerebellum is partly visible externally as **corpus cerebelli** and its anterior part enters into the cavity of optic lobes in the form of **vulvula cerebelli**. The corpus cerebelli consists of outer molecular layer and inner granular layer. The positin of layers is reverse in the vulvular cerebelli. The cavity of cerebellum (metacoel) is absent in fish. In mormyrids/Elephant fish (*Mormyrus*) the cerebellum is very well developed and is probably associated with the reception impulses from the electric organ of fish. Prominent, irregular projections called **auricular lobes** or **restiform bodies** present in certain fishes (*Squalus acanthias*) and continuous with the medulla oblongata, are actually parts of cerebellum. These are centre of equilibration.

The body of toad and frog is broad and less height, already in stable equilibrium and for this reason, the cerebellum is poorly developed.

The greatest advance in the cerebellum of higher forms is the appearance of a pair of **floccular lobes** near the ventral side. They correspond to the auricular lobes of fishes and first appear in crocodilians.

In birds and mammals, the cerebellum consists of a prominent middle portion, the **vermis** with floccular lobes on either side. The cerebellar cortex (gray matter) of the cerebellum covers the white matter and shows a complexity branched arrangement called the **arbor vitae**. The cerebellar cortex consists of 3 regions: deep granular layer (contains several types of cells), middle Purkinje's cell layer and superficial molecular layer (consists of fibers and synapses).

In mammals, the vermis is divided into anterior, middle and posterior lobes. The bilateral extensions of middle lobe are **cerebellar hemispheres**. The surface of the cerebellum is thrown into numerous folds or **gyri**, separated by deep grooves or **sulci**. The ventral side of the metencephalon is marked by a conspicuous **pons**, composed of a prominent mass of transverse nerve fibers.

Myelencephalon

The myelencephalon is the last part of the brain. The medulla oblongata is situated beneath and behind the cerebellum and continuous to the spinal cord.

The lateral and ventral walls of the medulla thicken but the dorsal wall retains its epithelial character. The piamater, a vascular membrane surrounding the brain, fuses with the brain roof. Vascular folds of the telachoroidea extend into the fourth ventricle to form the **posterior choroid plexus**.

The thickened ventral and lateral walls of the medulla contain large white fiber tracts as well as several columns of gray matter. In higher vertebrates, the integrity of the columns of gray matter in the brain is lost and a separation into various nuclei has occurred.

The VI-XII cranial nerves are associated with the medulla oblongata. It contains important nerve centers, which control regulation of heartbeat, respiration and metabolism.

In fish medulla oblongata is broad in front and has one medial facial lobe and two lateral vagal lobes. The vagal lobes are gustatory center of medulla oblongata and are better developed in species, depending upon taste for feeding. Facial lobes are prominent in species that search their food exploring the surrounding with the help of barbels.

The dorsal anterior portion of the medulla oblongata is referred to as **acousticolateralis area**. This area contains nuclei associated with nerves from the lateral line system and the inner ear. In terrestrial vertebrates it is associated with the equilibratory and auditory functions of the ear.

Suggested Books:

- Elements of Chordate Anatomy: C. K. Weichert and W. Presch
- Comparative anatomy of the Vertebrates: George C. Kent and Larry Miller
- Integrated Principles of Zoology: Cleveland P. Hickman Jr., Larry S. Roberts, Allan Larson and Helen I´ Anson

- Vertebrates - comparative anatomy, functional evolution: Kenneth V. Kardong
- The Vertebrate Body: Alfred Sherwood Romer

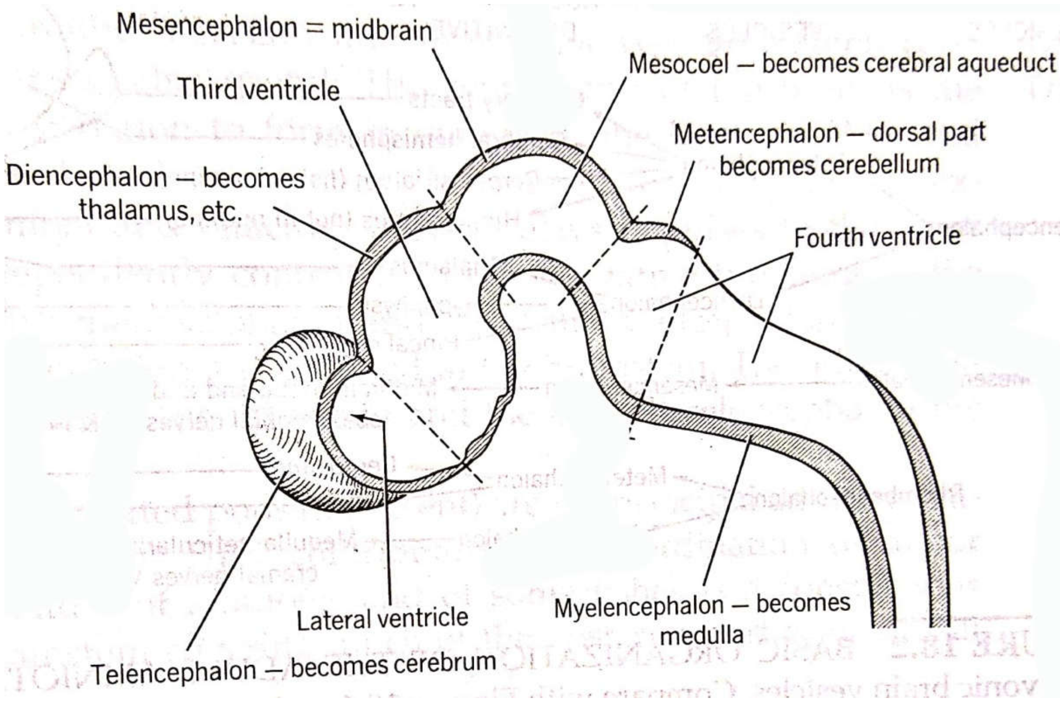


Fig. Development of mammalian brain

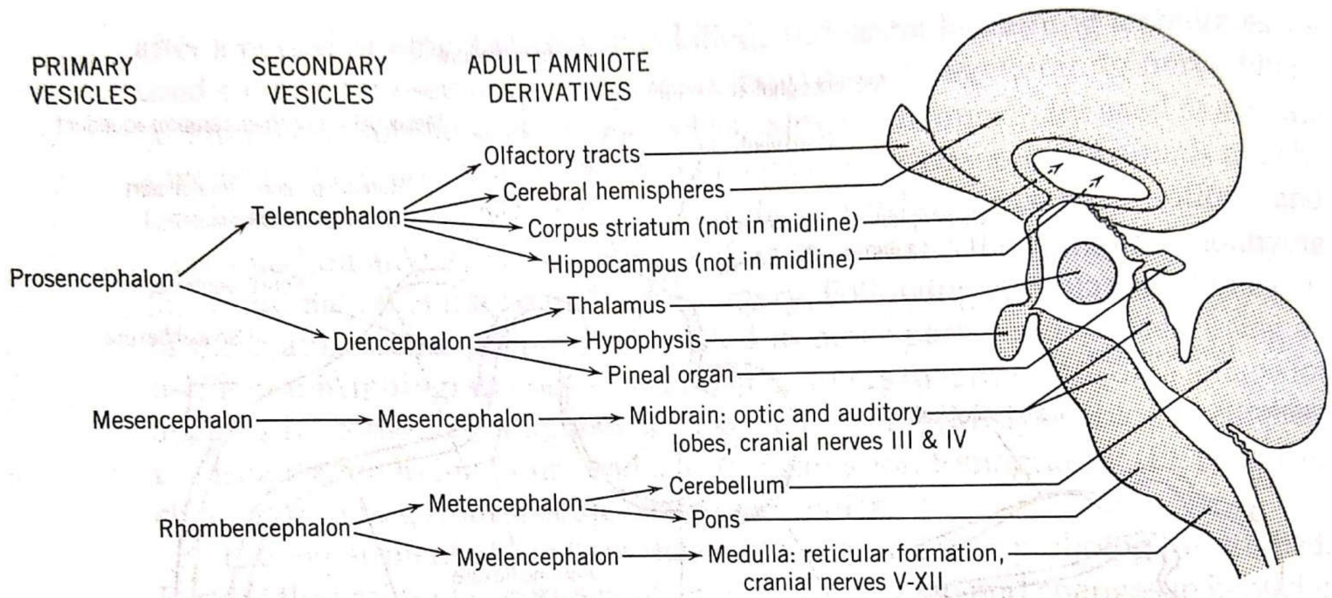
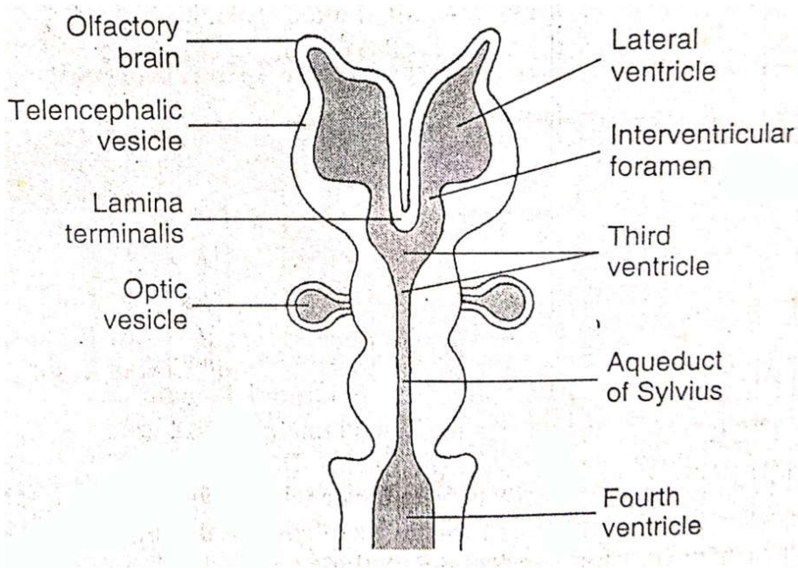


Fig. Basic organization of adult amniote brain



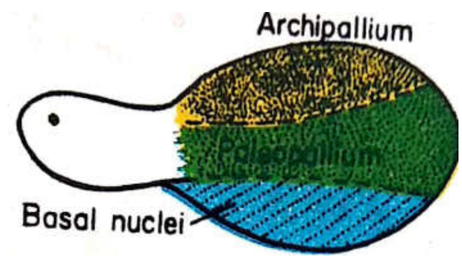
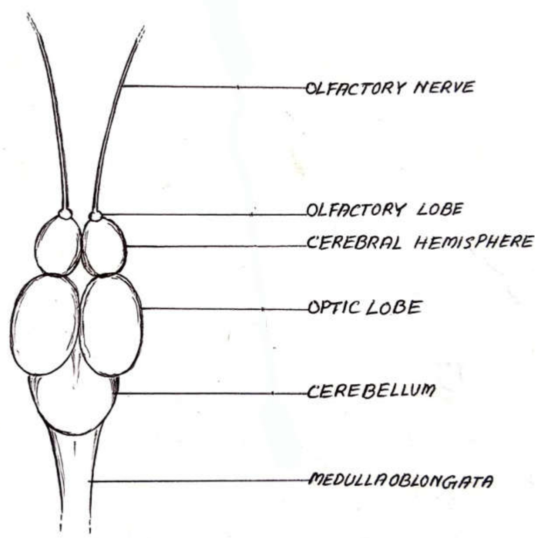
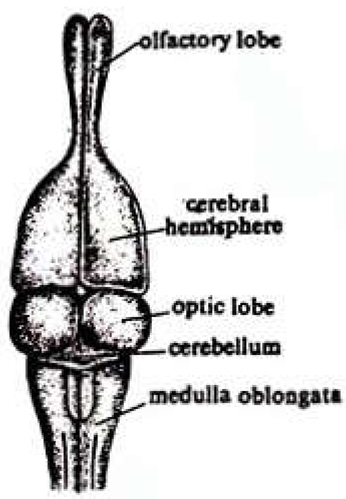


Fig. Cerebral hemisphere of ambhibians: dorsal and ventral areas, archipallium (=hippocampus) and basal nuclei (corpous striatum) are

Fig. Initial formation of brain





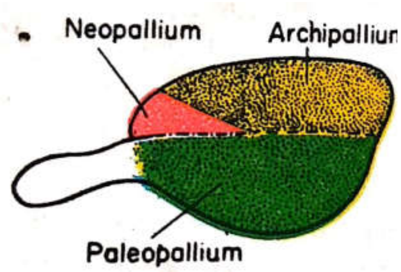
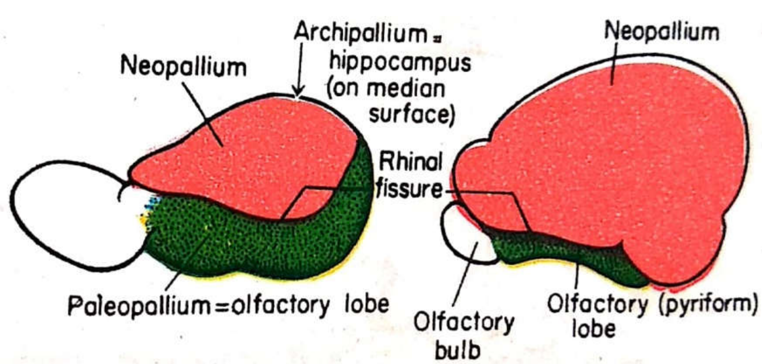


Fig. Cerebral hemisphere of reptiles: neopallium appears as a small area

Fig. Brain of carp

Fig. Brain of calotes



Primitive mammal Advanced mammal

Fig. Shows progressively differentiation of cerebral hemisphere

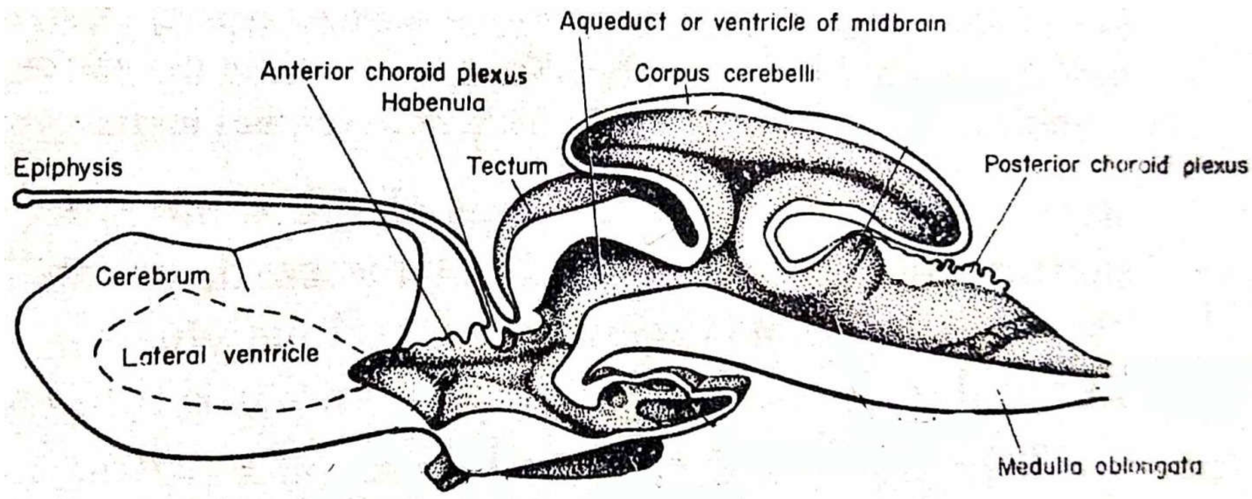


Fig. Brain of shark

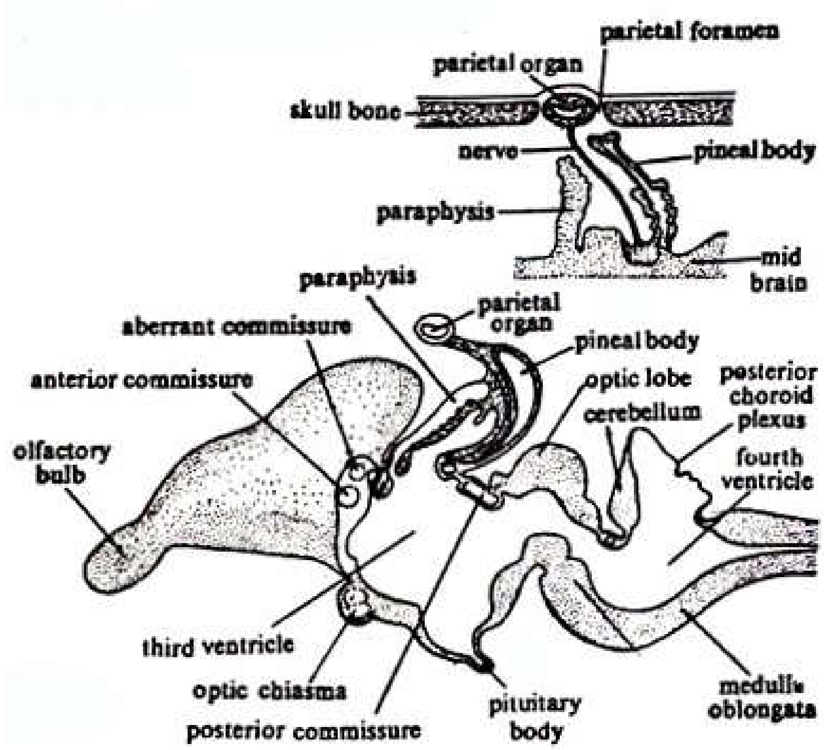


Fig. Brain of calotes

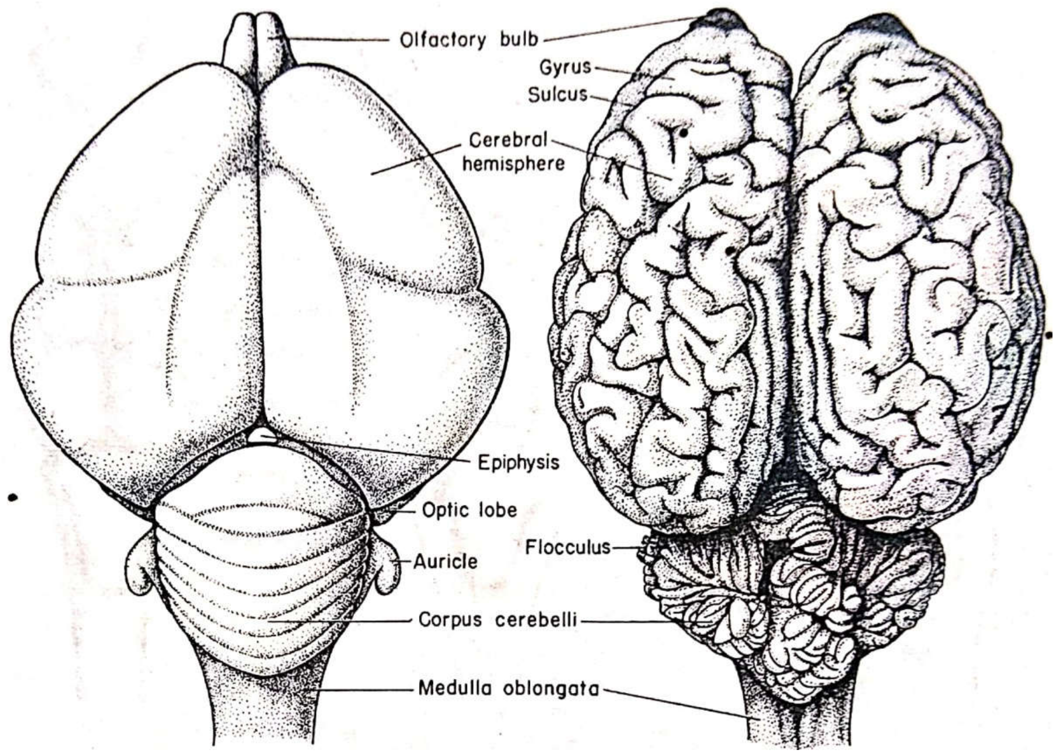


Fig. Brain of a goose

Fig. Brain of a horse

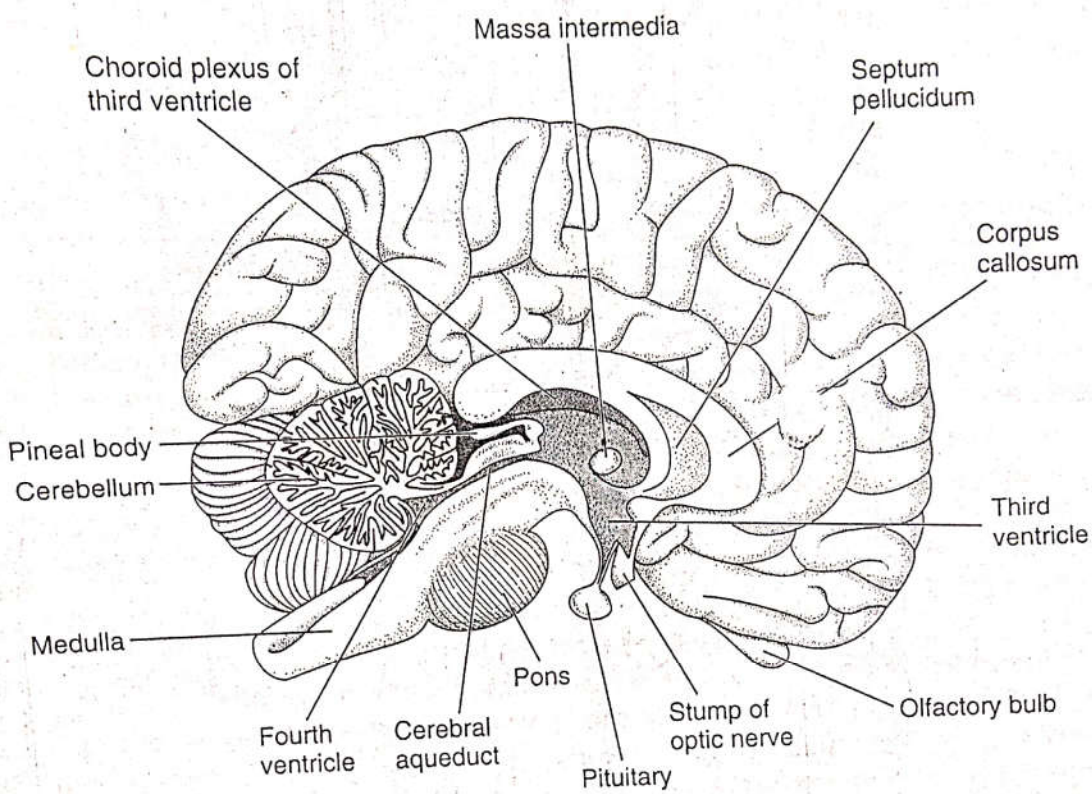


Fig. Sagittal section of human brain

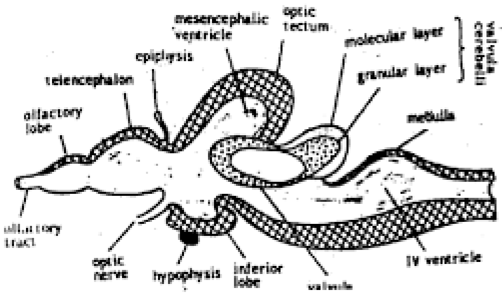
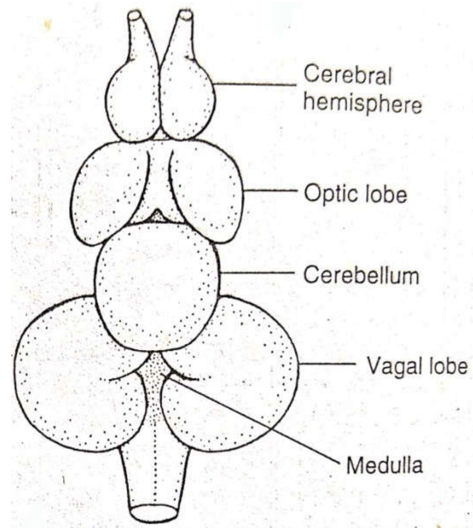


Fig. Brain of *Puntius ticto*



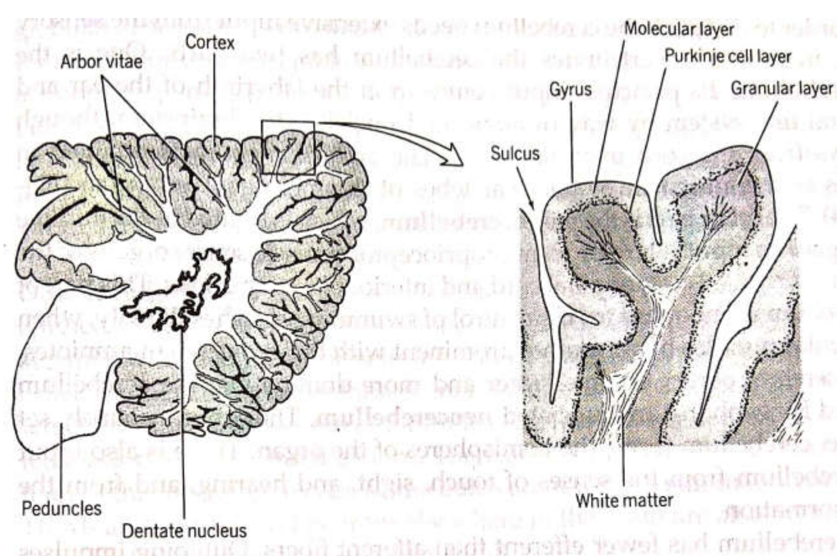


Fig. Section of human cerebellum

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"Don't believe in luck, believe in hard work"

Dentition in Mammals

Teeth are present in all mammals except some specialized forms. The adult platypus (*Ornithorhynchus*) bears epidermal teeth but no true teeth. In Echidna or spiny ant-eater (*Tachyglossus*) the teeth are absent in all stages of life. The arrangement of teeth in the upper jaw and lower jaw of gnathostomes is called **dentition**. The dentition in mammals varies according to their feeding habits. Teeth are developed partly epidermis and partly from underlying dermis.

Structure of a typical tooth

A typical mammalian tooth is distinguished mainly into two regions: crown and root. The part of the tooth *i.e.* above the root and ultimately subject to wear is the **crown**. The **root** is hidden below the gum and usually anchored to a jawbone. The junction of crown and root is called neck.

The tooth encloses a **pulp cavity** that contains blood vessels, nerves, and connective tissue. The pulp cavity is lined by a layer of bone cells, called odontoblasts.

The crown of the tooth is covered by a thin, very hard, glistering layer called **enamel** (very hard structure). Enamel is composed of crystals of hydroxyapatite [$3(Ca_3PO_4)_2$. $Ca(OH)_2$) and totally acellular. Below enamel, a hard dermal bony substance layer is found, called **dentine**. It is harder than bone but softer than enamel. The neck and the root are covered by a thin layer of **cement**. Cement is a nonvascular bone and usually acellular. It is softer than dentine and is rich in collagenous fibres.

The parts of teeth developed from the ectoderm is enamel and remaining dentine, cement and pulp are formed from the adjacent mesodermal tissues.

Types of dentition in mammals

A. According to the mode of attachment of teeth:

1. Acrodont (= summit + tooth)

The teeth have no roots and directly fused to the underlying jawbones *e.g.,* fishes, amphibians and some reptiles (Calotes, Draco). Not found in mammals.

2. Pleurodont (= side + tooth)

The teeth are attached to the inner side of the jawbone. The tooth touches the bone only with the outer surface of its root. *e.g., Necturus* and some reptiles.

3. Thecodont (= sheath + tooth)

Thecodont type dentition is the rule among mammals. The teeth are lodged in bony sockets or alveoli of the jaw bone. Capillaries and nerves enter the pulp cavity through the open tips of the hollow roots.

B. According to the succession or replacement of teeth:

1. Monophyodont

In some mammals, only one set of teeth develops in their lifetime. *e.g.,* some rodents (squirrels), certain insectivores (moles).

2. Diphyodont

In most mammals two sets of teeth are found. The first temporary set of teeth, called **deciduous teeth**, **milk teeth** or **lacteal teeth**, are lost or replaced by a second set of teeth, termed **permanent teeth**. In bats and guinea pigs the milk teeth are lost even before birth. In milk teeth the molars are absent.

3. Polyphyodont (= many + to grow + tooth)

The teeth are replaced continuously throughout life. *e.g.,* most lower vertebrates (Dogfish, snakes).

C. Classification according to the shape and size of the teeth

1. Homodont (= same + tooth)

The teeth are similar in shape as found in dolphins.

2. Heterodont (= different + tooth)

Heterodont condition is the usual feature in mammals, *i.e.* the teeth are distinguished according to their shape, size and function. In heterodont dentition, teeth are differentiated into four types:

2.1. Incisors

They are situated anteriorly on the premaxilla in upper jaw and tips of dentaries in lower jaw. Each incisor has a horizontal cutting edge and a single root. They are conical, single-rooted and monocuspid. <u>They are used for cutting or cropping</u>.

Incisors are best developed in herbivorous mammals. They may be conical spine like for holding insects or flesh or for cutting plant stem. Incisors of rodents and lagomorphs are exceptionally sharp and powerful. Incisors may be totally absent in sloth; absent on upper jaw in bovines; absent on lower jaw in case of vampire bat. Elephant tusks are modified incisors made up of solid dentine.

2.2. Canines

Canines lie immediately behind the incisors and in front of the premolars. They are spike like, long-crowned with a single root. <u>They are used for piercing and tearing the flesh of the prey</u>. Sometimes the canines are used in holding the prey, mainly seen in carnivorous mammals. In general mammalian dentition, incisors and canines are hardly differ in morphological appearance. The canines are always 1/1 in number if not reduced or lost.

In rodents and lagomorphs, the canine is absent, leaving a space in-between incisors and premolars, called **diastema**. In horses, the canines are relatively small. In flesh eating carnivores (dogs, tigers and lions) the canines are best developed, become spear-shaped and used for piercing and tearing the flesh.

In case of walrus, the tusks are modified canine.

2.3. Premolars

Following the canine, a series of premolars have two roots. <u>The premolars are used for grinding the food materials</u>. They are generally vary from 2-4 in numbers. The premolars of most mammals other than ungulates have two prominent cusp-hence, called **bicuspid**.

When the general shape and structure of the premolars assume molars-are called **molar formed** (*e.g.*, horse).

2.4. Molars

All non deciduous teeth of the first generation are called molars. Molars lie behind the premolars. They have two or more roots and several cusps (typical number 3 hence called tricuspid). Molars are used for crushing food. Premolars and molars are collectively called Cheek teeth.

In carnivores the number of cheek teeth is often reduced and in some cases (Fissipedia) last upper premolar and first molar in lower jaw are modified into chisel-shaped sharp cusps, called Carnassial teeth, used for cracking bones and shearing tendons. The molars are each jaw of man are called wisdom teeth and its eruption is often delayed.

Cusp patterns of cheek teeth:

The molars contain many cusps on their surface. The cusps are raised tiny structures or ridges on the occlusal surface. The cusps are called cones. Depending on the number and shape of the cusps, molars are recognized in different names.

[Among fossil mammals]
(i) Triconodont

Molars possess 3 cones or cusps arranged in anterior-posterior lines. Found in the fossil Mesozoic mammals, *e.g.,* Triconodon

(ii) Trituberculate

The molars contain three cones or tubercles, arranged in the form of a triangle. Found among fossil Mesozoic mammals, *e.g.,* Spalacotherium.

Depending upon the feeding habit and the type of food taken, the premolars and molars of recent eutherians have undergone changes in their shape, and cheek teeth are recognised into the following names:

(iii) Bunodont (mound + tooth)

In mammals with a mixed diet, the cusps tend to become low and rounded, forming hillocks on the crown, known as bunodont. In man and in some omnivore mammals the cheek teeth are bunodont type and they are used in grinding the food material.

(iv) Lophodont

If the cusps are joined to form ridges or lophs, the tooth is called lophodont. The cheek teeth of elephant are of lophodont type. There is an intricate folding of enamel and dentine. These type of teeth are used to grind all sorts of plants and also grasses.

(v) Secodont

When the cheek teeth are with sharp cutting crowns are called secodont. This condition of teeth is present in terrestrial carnivores. These teeth possess cutting edges and are used for cutting and shearing the flesh.

(vi) Selenodont (crescent shaped moon + tooth)

Cheek teeth with crescent-shaped cusps are known as selenodont. In ruminants and horses (perissodactyla), the teeth are selenodont type and are specialized for grinding the plant matter.

(vii) Brachydont (short + tooth)

A tooth with a low crown and comparatively long root is called brachydont. *e.g.*, Man.

(viii) Hypsodont

When the crown is high and the roots are short and open. *e.g.,* Horse, incisor of elephants.

Modification of teeth based on diet

The teeth of mammals are modified according to their food habit.

1. Herbivorous mammals

Foods consist of mainly grasses and plant material which require long mastication for digestion. In artiodactyles the grinding teeth possess broad crown, complicated by ridges and folds of hard enamel. Premolars are not used for grinding purposes.

- Among ruminants, the incisors of the upper jaw are lost and the canine teeth are rudimentary or absent. The incisors and canines of the lower jaw are present and are used for grass-cropping apparatus. The check teeth of ruminants and horses are of selenodont type.
- In male musk deer, the upper canine is projected downward from the mouth and form the characteristic musk tooth.
- Rodents have no canines. Only incisors are used for gnawing, scraping and nibbling. The incisors are sharp and chisel-shaped, used for cutting purposes. Enamel are absent on the posterior surface of the incisors and as a result, the body of the incisors wears quickly.
- Elephants have lost all canine teeth and all the incisors except the second pair in the upper jaw, which have developed into **tusks**. The jaws have six hypsodont molars in each jaw and are used as grinding teeth. Out of 6, only two molars remain functional at a time.
- In horses, all the cheek teeth are hypsodont with crescent shaped cusps, known as selenodont used for grinding purposes.

2. Carnivorous mammals

In carnivorous mammals, the canines are large, sharp and pointed which are used for tearing purposes and incisors are pierced into the body of the victim. These teeth are supported by powerful jaw muscles. Incisors and canines are used for seizing, holding and biting.

- Most of the carnivorous possess carnassial teeth. The last upper premolar and first lower molar together form sharp chisel-shaped structures, called **carnassials teeth**, used for cutting the flesh. These carnassial teeth act against each other like the blades of a pair of incisors.
- In walrus, the upper canine teeth are developed into downward pointing tusks and used for digging for bivalves.

3. Omnivorous mammals

The omnivorous mammals consume mixed diet including vegetables and meat. Cheek teeth of these mammals are bunodont type. The cusps on the cheek teeth remain separate and are rounded in shape. The incisors are used for cutting the food material. They have broad-crowned many cusped molars. The molars are designed to cut the flesh and to grind the vegetable matter.

4. Aquatic mammals

Among mammals, cetacean pinnipeds and sea cows are aquatic. The sea cows have teeth which are greatly reduced in size. They are grazers and teeth are little used. The well developed lips are used for grazing purpose.

The pinnipeds have teeth which have laterally compressed cones and three cusps in a row which helps to prevent escape of the slippery prey.

Cetaceans have two groups: bone whales (Mysticeti) and toothed whales (Odontoceti). Toothed whales have homodont type teeth. The teeth are used to hold the prey.

In bone whales (Mysticeti) the teeth are completely absent. Instead, transversely arranged triangular plates of keratin hang from the roof of the mouth, called **baleen**. The number of plates is about 300 and varies in colour in different species. The outer surface of the baleen is smooth and straight but inner surface has a hairy fringe to trap the food when water is expelled. These plates help to strain the minute planktonic food.

5. Insectivorous mammals

In Moles (*Talpa*), shrew (*Sorex*), the upper and lower incisors meet precisely for efficient capturing of small prey like insects.

Dental formula

Dental formula expresses the number of each type of teeth in each half of the jaws (both upper and lower) in a succinct fashion. The dental formula =

$$\frac{\text{No of teeth on the one half of upper jaw}}{\text{No of teeth on the one half of lower jaw}}$$

A typical primitive eutherian mammal possesses 44 teeth and it is expressed as
$I^3/_3\ c^1/_1\ pm^4/_4\ m^3/_3$ or 3.1.4.3/3.1.4.3 = 22 × 2 = 44 (I-Incisor, C-Cananine, PM-Premolar, M-Molar).

Among monotremes, *Tachyglossus* does not possess teeth at any stage. The adult platypus (*Ornithorhynchus*) bears no teeth.

In marsupials the milk dentition persists except the last premolar. In adult marsupials the number of incisors in upper and lower jaws always varies except in burrowing wombats (*Phascolomys*).

Reference Books:

- Analysis of Vertebrate Structure: Milton Hildebrand
- Comparative anatomy of the Vertebrates: G. C. Kent and R. K. Carr
- Vertebrates - comparative anatomy, functional evolution: Kenneth V. Kardong
- Elements of Chordate Anatomy: C. K. Weichert and W. Presch

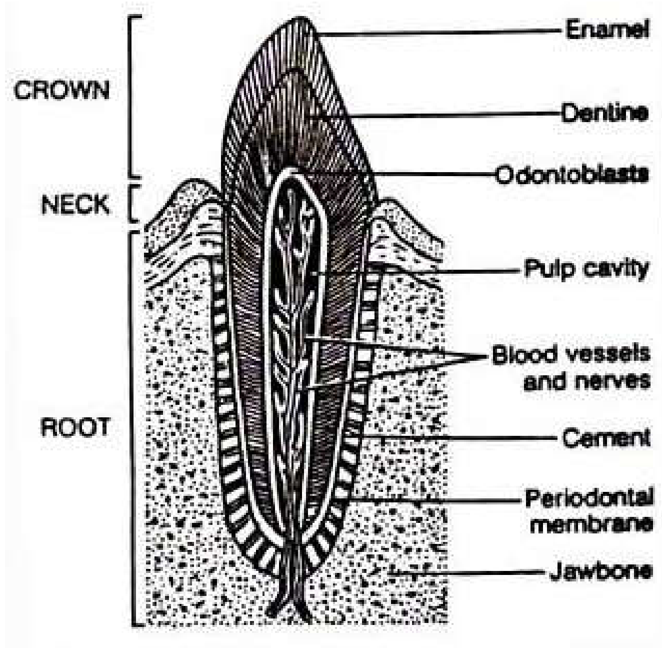


Fig. :Structure of a tooth showing its relation with the jaw bone.

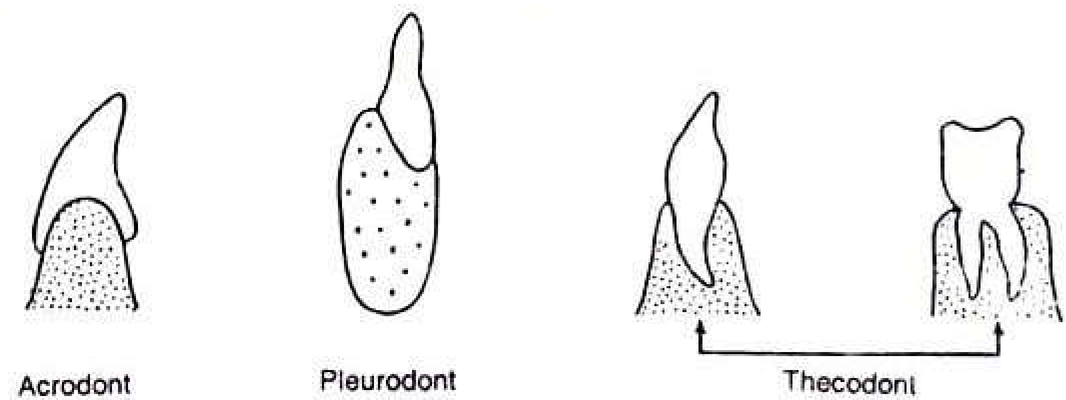
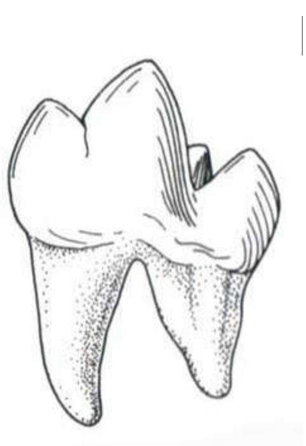


Fig. Mode of attachment of teeth.



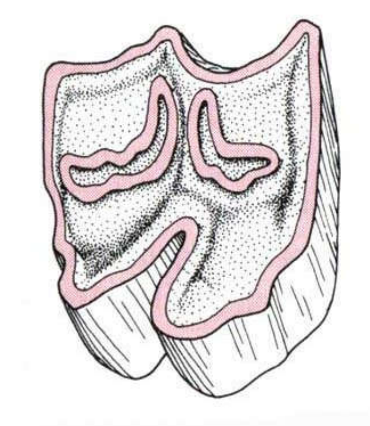


Fig. Secodont molar in carnivores

Fig. Selenodont molar in ruminants

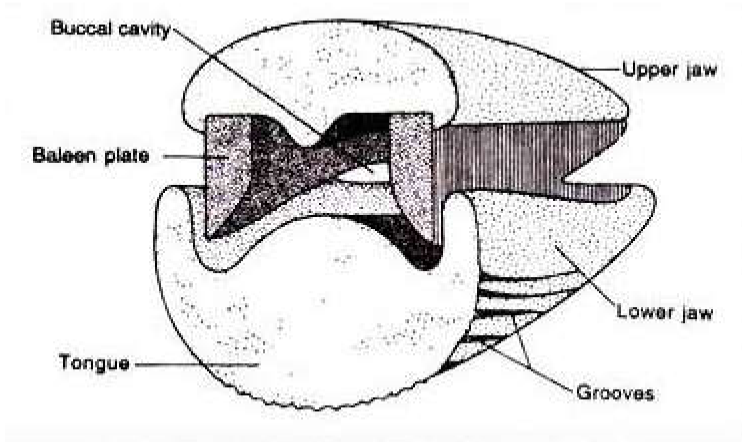


Fig. Sectional view of the head of a rorqual whale.

Kangaroo (*Macropus*) $\frac{3.1.2.4}{1.0.2.4} = 34$.

Family Suidae (e.g., Pigs) and horses bear primitive eutherian type of teeth.

Horses and Pigs $\frac{3.1.4.3}{3.1.4.3} = 44$.

Bat $\frac{2.1.0.4}{3.1.0.5} = 32$.

Old world monkeys $\frac{2.1.2.3}{2.1.2.3} = 32$.

Sheep, cow and goat $\frac{0.0.3.3}{3.1.3.3} = \frac{6}{10} = 32$.

New World monkeys $\frac{2.1.3.3}{2.1.3.3} = 36$.

Except common marmoset, *Callithrix* $\frac{2.1.3.2}{2.1.3.2} = 32$.

Cat $\frac{3.1.3.1}{3.1.2.1} = \frac{8}{7} = 30$.

Dog and Bears $\frac{3.1.4.2}{3.1.4.3} = \frac{10}{11} = 42$.

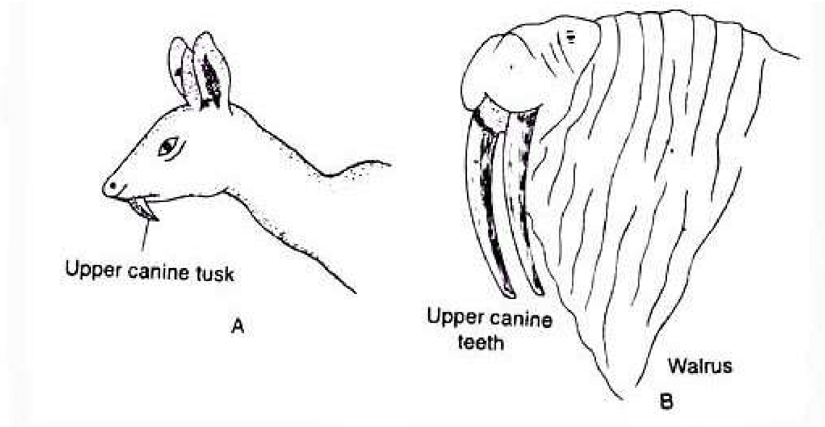
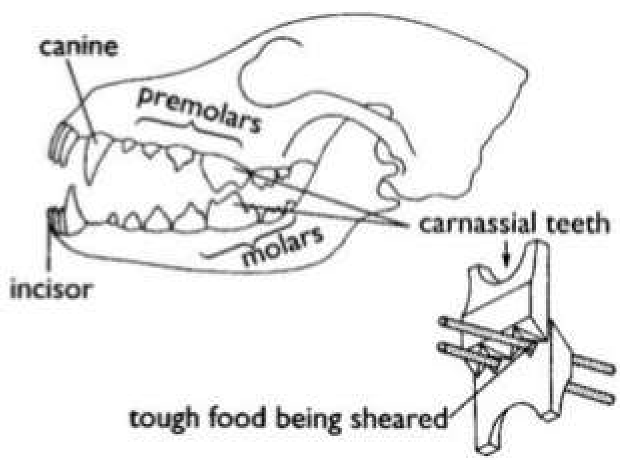
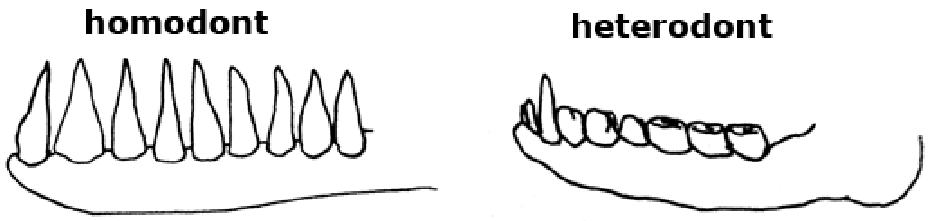


Fig. (A–B) : A. Tusk of male musk deer, B. Tusk of walrus. The tusks are modified upper canine teeth in both cases.

Carnassial teeth

- slide past each other in a scissor-like fashion as the mouth is closed
- are adapted for shearing flesh





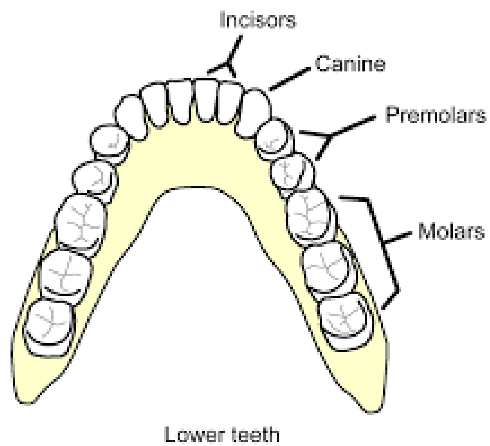
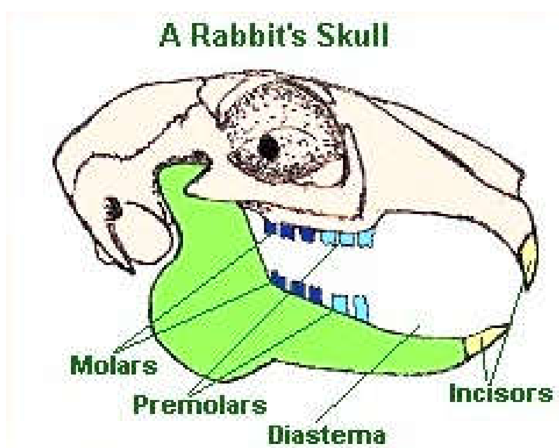


Fig. Dentition in human



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"Honesty is very expensive gift"

Respiration in Amphibians

Amphibians have the most complicated respiratory organs primarily because the amphibian includes all those animals, which live partly in water and partly on land. Their skin is usually soft, glandular and moist lacking in external scales. Hence, amphibians respire through skin, external gills, internal gills, lining of buccopharyngeal cavity and the lung.

Gills

Respiration by gills called branchial respiration. Gills are of two types:

(i) External gills which project from the surface of the pharynx towards water surface and are rhythmically moved by the branchial muscles for ventilation. External gills persist throughout life in neotenic salamanders (*e.g., Necturus*); frog tadpole first develop external gills which are replaced by internal gills later. Few urodeles retain external gills as the respiratory organs in adults.

In tadpole, before gill slits perforate, external gills develop as fingerlike elevations on the outer surfaces of visceral arches III–V. A rudimentary gill may develop on VI arch.

(ii) Internal gills: From hyoid arch, a fleshy operculum grows backward over the entire gill apparatus and encloses it in an opercular cavity. Internal gills serve throughout the most tadpole stage. In larval urodeles and caecilians, a vestigial operculum makes an appearance, but it becomes only a small fold on hyoid arch.

Gill lamellae are richly supplied with blood vessels, in which blood flows in opposite direction to the flow of water. Water is drawn into gills >> blood flowing in the capillaries of gill lamellae absorbs oxygen from water and release CO_2 >> water containing CO_2 is thrown out from gills. The 80% of incoming water is absorbed.

Skin

In many larvae and adults the skin is an important respiratory organ. Skin is thin and richly supplied with blood vessels, serve as a gas-exchange organ whenever the animals are under water or in extremely moist places. Tadpoles, salamander larvae and a few types of adult salamanders breathe primarily through their gills. However, they can get rid of excess carbon dioxide through their skin.

Where presence of an air-bubble lung is maladaptive to locomotion, have lost lungs and respiration is **cutaneous,** exhibits a remarkable supplementary respiratory adaptation. For salamanders living in quiet water the lungs have some respiratory function, but are more important as hydrostatic organs similar to the swim bladder of teleost. There are vascular folds in the epidermis into which blood capillaries penetrate.

Buccopharyngeal lining

The buccopharyngeal membranes are vascular, serve as a respiratory surface in a wide variety of amphibians. In some species that remain submerged in water for long periods, gas exchange by buccopharyngeal lining play a significant role.

Buccopharyngeal cavity provides a small percentage of gas exchange in some lungless plethodontid salamanders.

In frog, buccopharyngeal respiration occurs when the frog is not submerged in water. The lining of mouth is very moist and can be used to bring oxygen into the blood stream by dissolving and diffusing into the blood capillaries.

Lungs

Adult amphibians are lung-breathers. As in all tetrapods, the amphibian lung develop from the floor of the alimentary canal just behind the gill slit region. They are supplied with blood by derivatives of the arteries to the last gill arch and drained by the pulmonary vein, which go directly to the heart. The lungs lie within the pleuroperitoneal cavity and visceral peritoneum except anteriorly where they are attached to the anterior walls of the body cavity. The lumen of each lung is continuous, either directly or through very short bronchi, with the laryngeal chamber, a mid line structure deep to the floor of the pharynx lined with muscles and small cricoid and arytenoids cartilages. The cartilages surround a slit-like opening into the pharynx, called the glottis, which is controlled by laryngeal muscles attached to the laryngeal cartilages. In most tetrapods the glottis opens in the floor of the pharynx, just anterior to the opening of the oesophagus.

In amphibians, however, there is a deep concavity in the floor of the oropharynx (particularly prominent in anurans and the position of the glottis is shifted to a posterior vertical surface of this concavity, just ventral to the oesophagus).

During respiration, sphincter muscles close the oesophagus. The internal complexity of the lung and hence, extent of its respiratory membrane vary according to the order. Septae support the vascularized respiratory membrane and divide the lung into inter-communicating air spaces called **infundibuli**. Each infundibulum is lined by a thin epithelium with capillary bed lying deep to it in connective tissue. There are also smooth muscles just deep to the vascularized layer. In frogs and toads the septae are more complex than in salamanders and caecilians; the septae divide the lung into more and smaller air spaces called **alveoli**, giving a larger total surface area for the respiratory membrane. Toads, whose keratinized skin permits little cutaneous respiration, have the most complex alveoli and the largest respiratory membrane.

Ventilation: Amphibians force air into their lungs by a pumping action of the floor of the oral cavity in association with the action of valves that surround the external nares.

During **inhaling**, the external nares are opened and the floor of the oral cavity is depressed by contraction of the mylohyoid (sternohyal) and other muscles. Atmospheric pressure forces the air into the oral cavity. The nares are then closed by smooth muscle action and the floor of mouth is elevated. This action forces the air in the only direction available, through the glottis and into the lungs. In male anurans, opening the entrance to the vocal sacs would also force air to enter those chambers.

During **exhaling**, the body wall muscles compress the content of the pleuro-peritoneal cavity and thus force the air up into the oral cavity. Petrohyal muscle contract and raise the floor of buccal cavity and pump air out. Sometimes the air may then be pumped back into the lungs again or released out through open nostrils. Urodeles gulp air as well as inhale via the external nares, but the floor of mouth must still force the air into the lungs. In exhaling, some urodels (e.g., *Siren*) with open gill slits eject the air forcefully through the slits.

- Tailed frog (*Ascaphus*), living in the mountain stream of U.S.A., has reduced lungs which help the animal to live in water.
- In perennibranchiate (retaining branchae/gills throughout life) urodeles, the lungs are simple saccular organs and performs hydrostatic function.
- In alpine salamander (*Salamandra atra*) and dusky salamander (*Desmognathus*), the lungs are absent.
- In *Astylosternus*, an African frog, the lungs are vestigial.
- In caecilians, the tracheal lung may be present but the left one is always rudimentary.
- In aquatic urodeles, the lungs act secondarily as hydrostatic organ.

In all these above, respiration is exclusively pharyngeal and/or cutaneous.

Frogs do not have the necessary chest and stomach muscles, cannot inhale and exhale as we do. Instead, they fill their mouth cavity with air, close their mouth, and force air back through an opening called the glottis into the lungs. The glottis then closes to keep the air in the lungs for a short time.

Frogs can also direct some of the air they take in to a pair of expandable vocal sacs, near their mouth. Frogs croak by forcing air from these sacs over vocal cords in their throat. By directing air back and forth through the throat between the vocal sacs and the lungs, frogs can even croak under water.

The production of sound is a protective response for fear and the males call the females during breeding season. The noise is produced by the vibration of the vocal cords in the laryngotracheal chamber. The vocal sacs in the males of some anurans, developed as the buccal outgrowths, serve as resonator. Sound produced by female anurans are of much less magnitude in comparison to males.

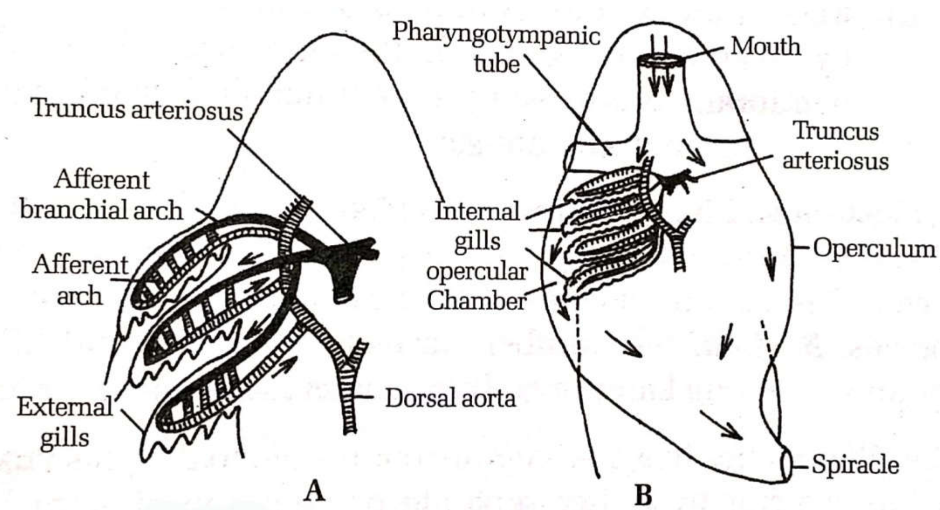

Figure
The tadpole of frog **A.** external gill stage **B.** internal gill stage

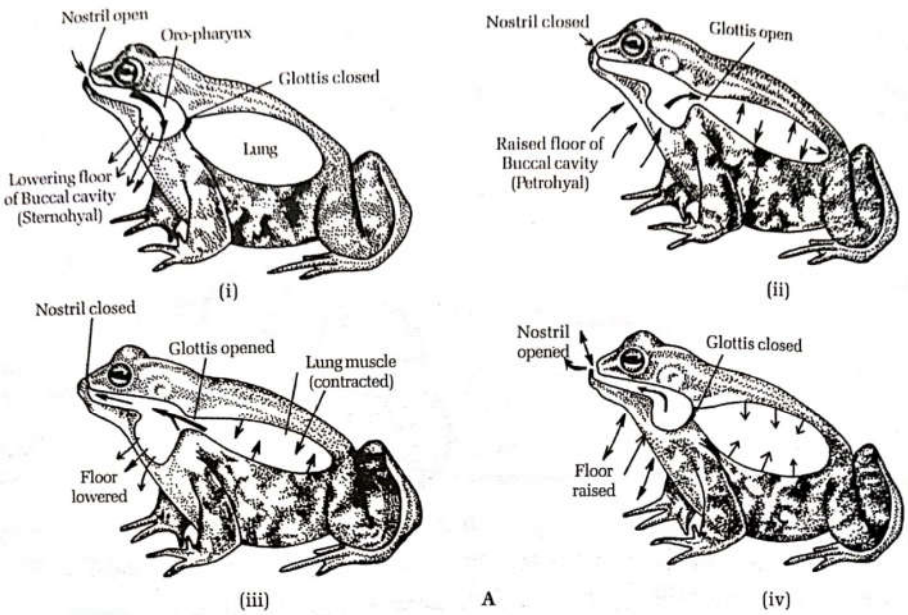

Figure
A. Ventilation of the lungs in a frog (thick arrow shows the inward movement of air) (Fig i, ii, iii and iv) show outward movement

- **i.** The glottis is closed, lowering the floor of the orpharynx draws air into cavity.
- **ii.** The nostril are closed and the floor of the orpharynx raised forcing the air into the lungs
- **iii.** The glottis is opened and lungs muscle contracted forcing air out through the glottis, orophaynx into buccal cavity
- **iv.** The glottis is closed and the nostrils opened, osscilatory movement of phaynx force air out through nostrils

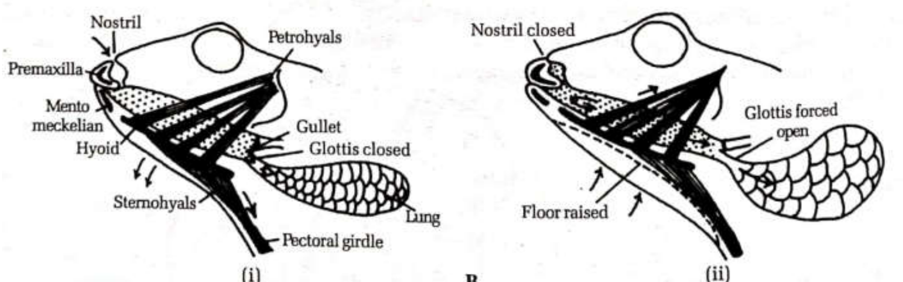

Figure
Muscle involved in inspiration during pulmonary breathing in frog (i) Floor of buccal cavity is lowered (Sternohyals) to draw air in through open nostrils, glottis is kept closed (ii) Nostril closed, floor is raised by petrohyals, glottis forced open, lungs inflated)

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- Comparative anatomy of the Vertebrates: R. K. Saxena and Sumitra Saxena
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"Honesty is very expensive gift"

Cranial nerves in mammals

The nerves, which arise from the brain and brain stem rather than spinal cord called **cranial nerves**. Nerves arising from the spinal cord are the **spinal nerves**. There are 10 pairs of cranial nerves in anamniotes and 12 in amniotes. Some are entirely sensory or entirely motor, but others are mixed nerves carrying both types of fibers. Cranial nerves are traditionally referred by Roman numerals and these numerals begin cranially and run caudally.

In 1894, a new cranial nerve was discovered connecting to the anterior end of the cerebral hemispheres. This nerve has been found in all gnathostomes except birds and is called **cranial nerve 0**.

Cranial nerves	Name	Type	Origin	Distribution
I	**Olfactory**	Sensory	Olfactory lobe	Nasal epithelium
II	**Optic**	Sensory	Optic thalamus	Retina of eye
III	**Oculomotor**	Motor	Ventral side of mesencephalon	inferior oblique, inferior rectus, superior rectus, internal rectus, iris, ciliary body
IV	**Trochlear**	Motor	Midbrain	Superior oblique eye ball muscles
V	**Trigeminal**	Mixed	Lateral side of anterior end of the medulla oblongata	
V_1	Ophthalmic	Sensory		Upper lip, nose, lower eye lid
V_2	Maxillary	Sensory		Upper jaw, vibrissae, nose
V_3	Mandibular	Sensory & motor		Lower jaw and lip, external ear, tongue
VI	**Abducens**	Motor	Ventral part of medulla oblongata	External rectus muscle of eyeball
VII	**Facial**	Mixed	Side of medulla oblongata	
VII_1	Palatine	Sensory		Roof of buccal cavity and nasal chamber
VII_2	Chorda tympani	Motor		Tongue, salivary glands, taste buds.
$VIII_3$	Hyomondibular	Motor		Lower jaw, neck, pinna, hyoid
VIII	**Auditory**	Sensory	Floor of Medulla	
$VIII_1$	Vestibular	Sensory		Internal ear
$VIII_2$	Cochlear	Sensory		Cochlea
IX	**Glossopharyngeal**	Mixed	Medulla	
IX_1	Lingual	Sensory		Tongue, pharynx, salivary glands
IX_2	Pharyngeal	Motor		Pharynx, salivary glands

Cranial nerves	Name	Type	Origin	Distribution
X	**Vagus**	Mixed	Posterior part of medulla	
X_1	Superior laryngeal	Motor		Muscles of larynx
X_2	Recurrent laryngeal	Motor		Muscles of Larynx
X_3	Cardiac	Motor		Heart
X_4	Pneumogastric	Mixed		Lungs, oesophagus, stomach, small intestine
X_5	Depressor	Motor		Muscles of diaphragm
XI	**Spinal accessory**	Motor	Medulla	Pharynx, larynx, neck, shoulder
XII	**Hypoglossal**	Motor	Medulla	Neck and tongue

Sensory nerve carries sensory information toward the central nervous system.

Motor nerve carries impulses from the brain or spinal cord to a muscle or gland.

Terminal nerve or Nervous terminalis (0)

The terminal nerve appears to originate in the diencephalon and passes to the olfactory mucous membrane. This somatic sensory nerve is best developed in elasmobranches. In amphibians, reptiles and mammals it is associated with vomero-nasal or Jacobson's organ, which seems to be accessory olfactory structure.

Olfactory nerve (I)

The olfactory nerve is composed of non-medulated afferent fibres originating from the olfactory lobe of the brain. The cell bodies of the fibres lie in the olfactory epithelium. The nerve proper usually consists of many separate fibres which are not gathered together in a sheath. However, in some forms, the olfactory nerve is rather long and joins the olfactory lobe, which is not differentiated into bulb and tract. In mammals as many as 20 separate nerve branches on each side pass to the brain.

Olfaction is part of the special senses cranial nerve group and represents the chemical senses of olfaction (smell) and gustation (taste). When chemical substances interact with bodies they stimulate special sensory cells which in turn generate an action potential. The resultant impulse is sent to the brain via sensory afferent fibres, represent the olfactory cranial nerve. The olfactory organ in dogs is extremely well developed and species such as canines use olfaction to orientate themselves in an environment.

Optic nerve (II)

The cell bodies of the optic nerve lie in the retina of the eye. The two optic nerves cross beneath the diencephalon to form the optic chiasma. The origin of optic nerve indicates that it is really not a nerve but a part of the brain, hence the name is usually termed **optic tract**. It carries impulses from the retina to the brain.

Oculomotor nerve (III)

It leaves the ventral side of the mesencephalon and is distributed to the inferior oblique, superior rectus, inferior rectus and internal rectus eye muscles. It is concerned with accommodation and regulates the size of the pupil.

Trochlear nerve/Pathetic nerve (IV)

It leaves the dorsal side of the mesencephalon. It is the smallest cranial nerves, enters the orbit and supplies the superior oblique muscle of the eyeball and concerned with movement of the eyeball.

Trigeminal nerve (V)

It is derived from lateral side of the anterior end of the medulla oblongata before it emerges from the skull. It bears a large Gasserian ganglion. The main nerve is divided into 3 branches:

Ophthalmic nerve (V_1): sensory nerve composed of somatic afferent fibres and passes through the orbital fissure. It enters the orbit of the eye and splits further into the lacrimal nerve, the frontal nerve, the nasociliary nerve and the infratrochlear nerve.

Maxillary nerve (V_2): main branch of trigeminal, divided into branches and supplies the skin over the upper jaw, upper lip, side of the nose, lower eyelid and teeth of upper jaw.

Mandibular nerve (V_3): mixed sensory somatic afferent fibres and motor somatic efferent nerves. It runs obliquely backwards in the orbit, then goes directly to skin above the lower jaw and muscles of lower jaw, used for chewing.

Abducens nerve (VI)

It arises from the ventral side of the medulla oblongata and supplies the posterior external rectus muscle of the eyeball. It is concerned with eye ball movement.

Facial nerve (VII)

It originates from the side of medulla oblongata, derives Gasserian ganglion. It leaves the medulla just behind the trigeminal and has several branches:

Palatine/Pharyngeal (VII_1): distributed to mouth and taste bud series, concerned with movement of facial muscle and taste sensation.

Chorda tympani (VII_2): passes through the middle ear. The chorda tympani supplies taste to the rostral 2/3 of the tongue.

Hyomandibular (VII_3): main branch, supplies to the tongue, muscle of lower jaw, salivary gland, scalp, external ear and superficial neck muscle. A geniculatee ganglion lies at the point where the hyomandibular branch leaves the medulla oblongata. It is concerened with common sensation and secretion of saliva.

Auditory/Vestibulocochlear nerve (VIII)

It arises from the medulla close to V and VII. This nerve bears an acoustic ganglion, which arises and is closely associated with the geniculate ganglion of the facial nerve. The nerve just after its origin divided into two components:

Vestibular (VIII$_1$): better developed, connecting with upper part of ear concerned with equilibration.

Cochlear/Saccular (VIII$_2$): connecting with the auditory part of the ear.

Glossopharyngeal nerve (IX)

It arises from the medulla. With loss of gills and neuromast in mammals, IXth nerve lost many fibers soon after its origin, divides into two branches:

Lingual (IX$_1$): sensory fibers supplying the back of the tongue

Pharyngeal (IX$_2$): visceral motor fibers supplying some muscles of pharynx.

Glossopharyngeal is concerned with contraction of pharynx and sensation of taste.

Vagus nerve (X)

The vagus arises from the medulla by lateral rootlets, distributes widely, serving areas of mouth, pharynx and most of the viscera. The vagus after forming vagus ganglion, sends a branch, called **Cardiac depressor** to the heart and a branch anterior laryngeal to larynx. After entering the thoracic cavity, vagus sends branches to lungs, heart and other visceral organ.

Superior/Anterior laryngeal (X$_1$): to the muscle of larynx.

Recurrent laryngeal (X$_2$): loops around the subclavian artery and passes forward to supply certain muscle of larynx.

Cardiac (X$_3$): bring impulses from the heart and aortic arches.

Pneumogastric (X$_4$): main nerve goes to form a series of plexuses in the visceral organs, such as oesophagous, lung, stomach and small intestine.

Depressor (X$_5$): to the muscle of diaphragm

Of all the cranial nerves, the vagus nerve is most vital one, because it controls heartbeat, peristalsis of digestive tract and respiratory movements.

Spinal accessory nerve (XI)

It originates from the lateral side of the medulla oblongata and innervates muscle in the neck region. Fibers pass directly to certain muscles of the pharynx and larynx. The spinal fibers of the nerve supply the sternomastoid and trapezius muscle.

Hypoglossal nerve (XII)

The hypoglossal is a somatic motor nerve, begins from the midventral region of medulla oblongata. Some fibers of hypoglossal together with fibers of certain spinal nerves form a plexus in the neck called **ansa hypoglossi**. It controls the intrinsic and extrinsic muscles of the tongue (together with other nerves including the lingual nerve, facial nerve, lingual branch of the glossopharyngeal nerve and the vagus nerve).

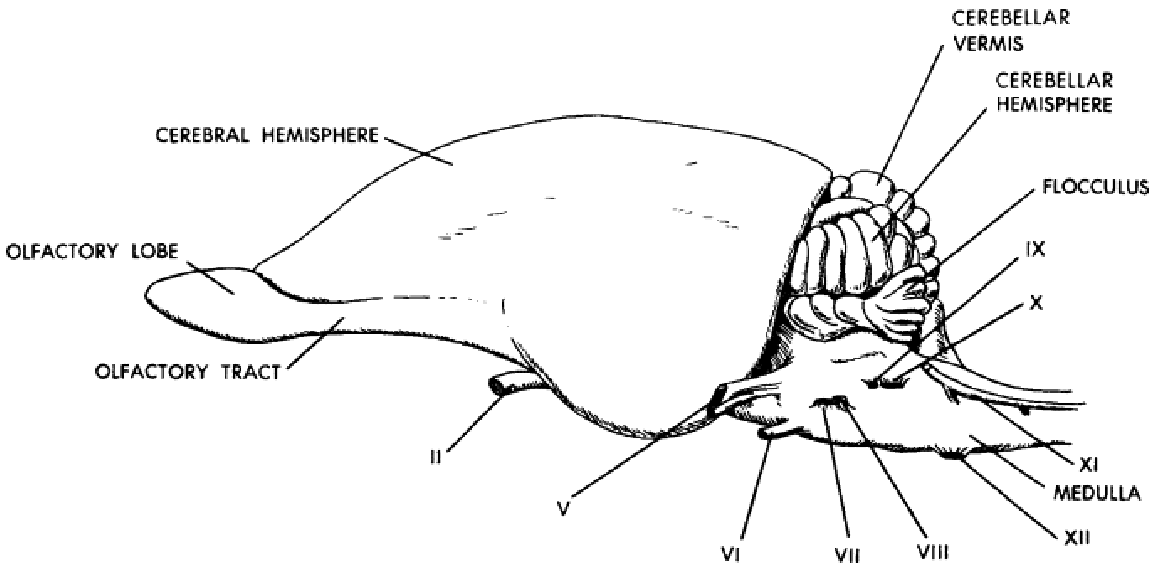

Fig. Distribution of cranial nerves in mammals

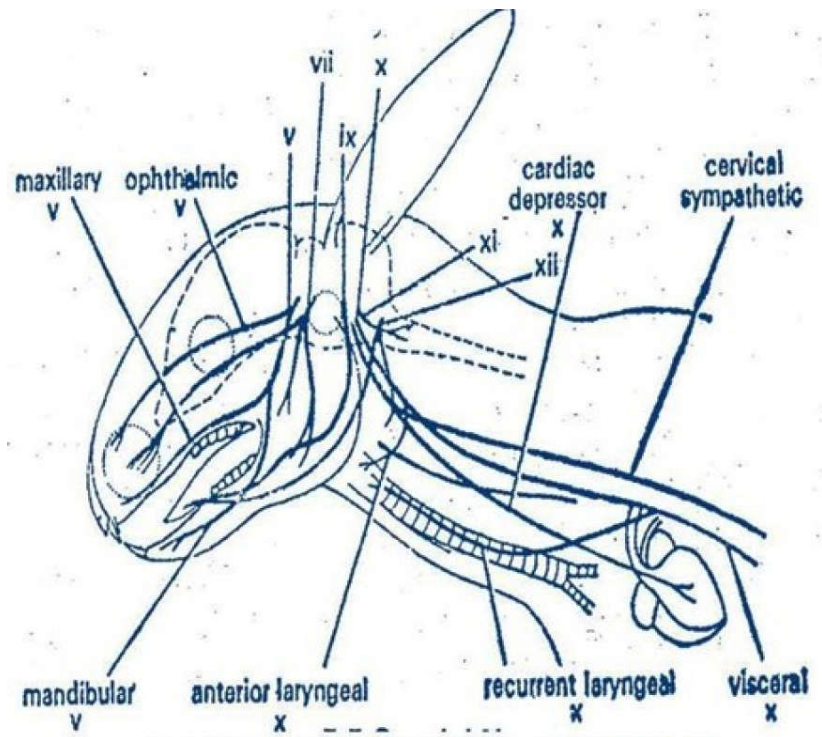

Fig. Distribution of cranial nerves in rabbit

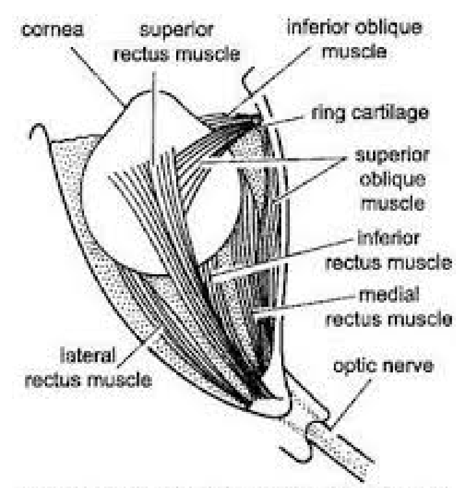

Fig. Optic nerve in rabbit

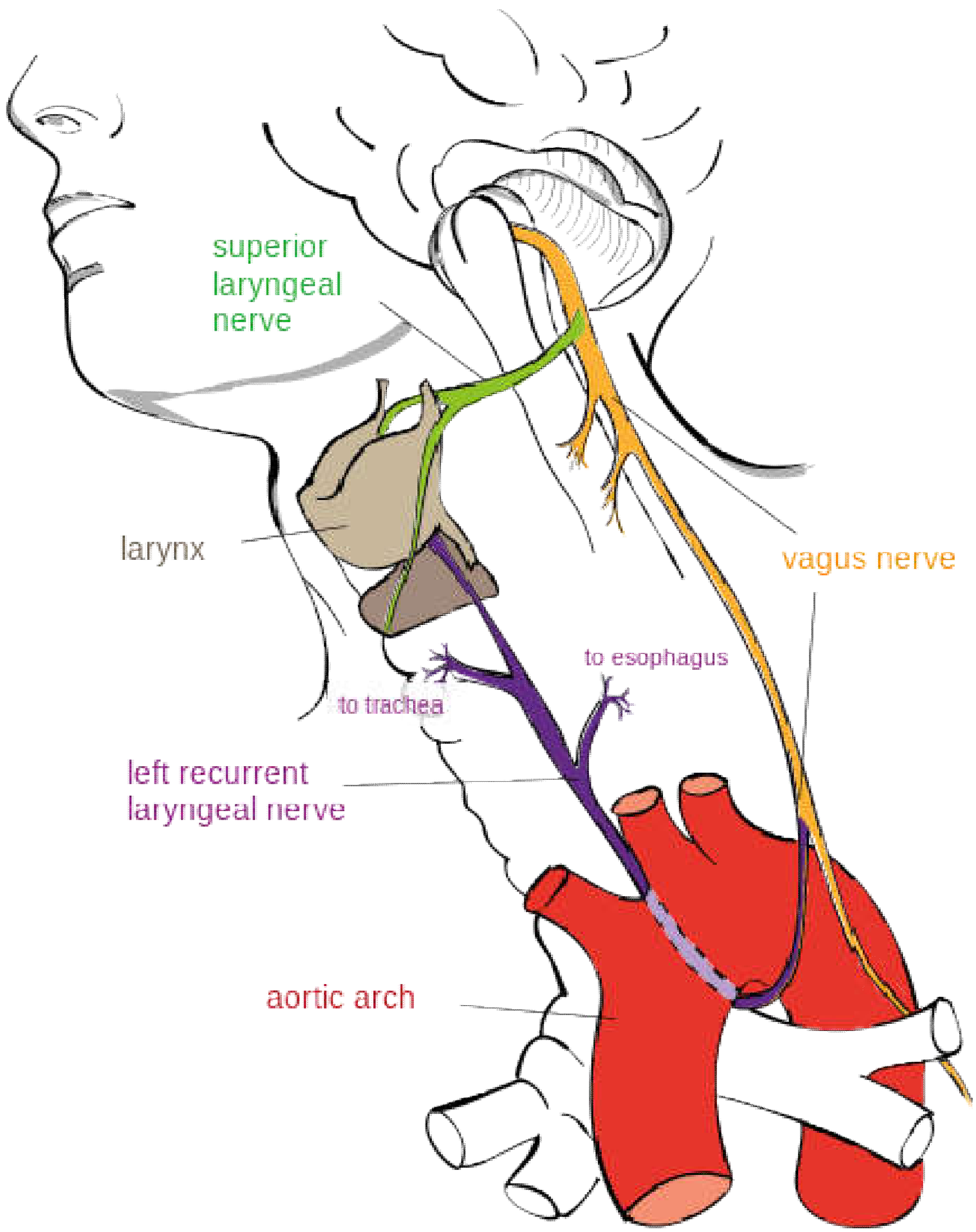

Fig. Distribution of cranial nerves in human

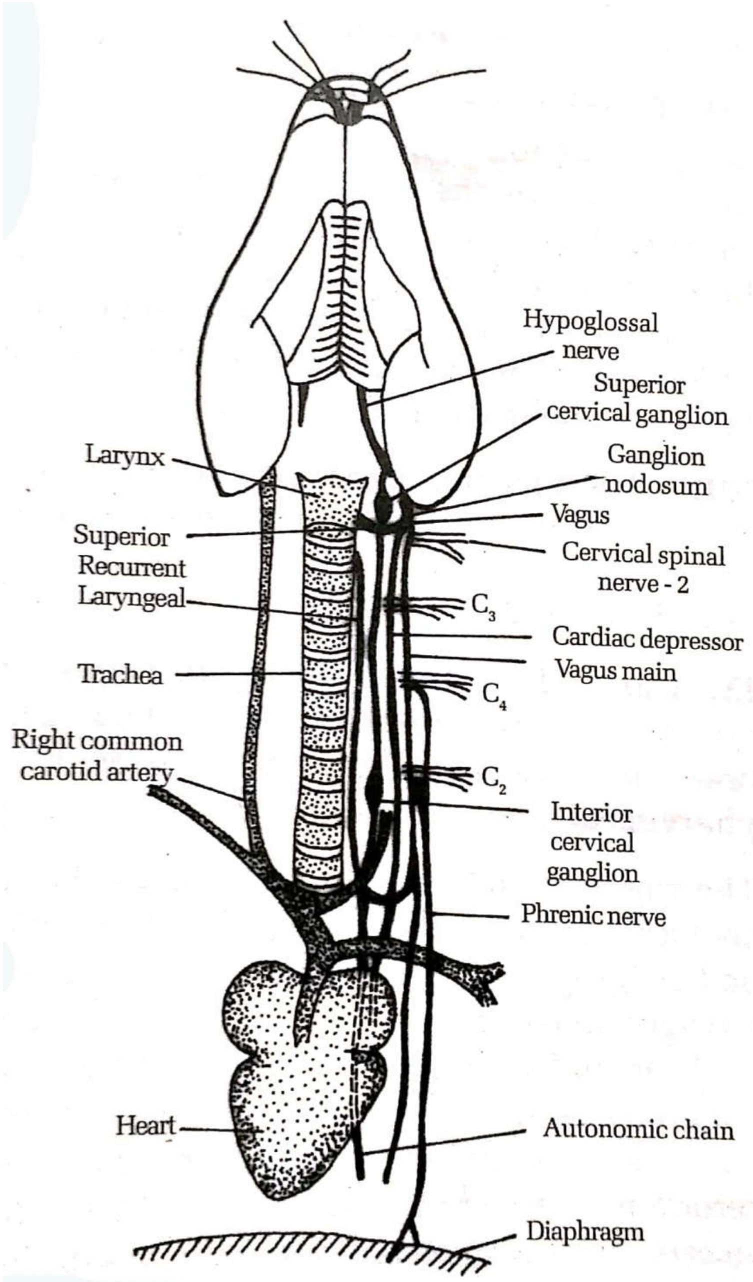

Fig. Distribution of cranial nerves in squirrel

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"Don't believe in luck, believe in hard work"

Respiratory organs if Fish

The respiratory organs of an animal are so constructed as to obtain necessary oxygen for the purpose of intracellular oxidation and the liberation of energy for the maintenance of life and to get rid of carbon dioxide. The respiratory and circulatory systems, although anatomically distinct, are functionally coupled in the process of **respiration**, the delivery of oxygen to tissues and the removal of waste products, principally carbon dioxide. **External respiration** refers to gas exchange between the environment and blood via the respiratory surface. External respiration is carried on through respiratory membranes. The chief organs of external respiration in adult vertebrates are external and internal gills, the oropharyngeal mucosa, swim bladders, lungs etc. External respiration precedes **internal respiration** which refers to gas exchange between the blood and the deep body tissues.

Ventilation or breathing is the active process of moving the respiratory medium, water or air, across the exchange surface. Ceasing the movement of the respiratory medium is **apnea** or breath holding. Pumping of blood through an organ via capillaries is known as **perfusion**. The respiratory organs specialize in ventilation to deliver oxygen and remove carbon dioxide accumulated during perfusion.

In most fish gills, ventilation is **unidirectional**. Water enters the buccal cavity through the mouth, passes across the row of gills known as the gill curtain, and exists flowing in one direction only.

Respiratory organs in fish

The main respiratory organs in a fish are the gills. The lateral walls of the pharynx are perforated by means of a series of slit-like apertures, the first of which is called the spiracle, lying between the mandibular and hyoid arches. The anterior and posterior wall of each gill slit is raised in the form of vascular filamentous outgrowths to form the gills where exchange of dissolved oxygen and carbon dioxide takes place. Besides the gills, other structures as the skin, air bladder and accessory organs also function as respiratory structures in some fishes.

1. Gills

Depending on the location of the gills, two types of gills are found in fishes.

1.1. External gills

Arise in the branchial region as filamentous capillary beds that protrude into surrounding water. They are found in the larvae of many vertebrates, including lung fishes and actinopterygians.

1.2. Internal gills

Covered and protected laterally by soft skin folds, such as the interbranchial septum in chondrichthyes or by a firm operculum in osteichthyes.

Internal gills are commonly classified in three categories according to arrangement and relation to supportive and protective tissue.

1.2.1. Pouched gills

Pouched gills are characteristic feature of agnatha. The gill filaments are arranged over the surface of discrete spherical pouch like gill chambers. Each pouch may has its own external pore (lamprey, *Petromyzon*) or the pouches on each sided of the body may communicate with the outside by a common duct and pore (Hagfish, *Myxine*).

1.2.2. Septal gills

Septal gills in chondrichthyes are differ from pouched gills in that the gill chambers tend to be larger to communicate more widely with the pharynx internally and to communicate with the outside of the body through vertical gill slits. Supportive tissues join the gill bars to the surface of the body and to form plate like gill septa. The first gill chamber and cleft of elasmobranches is reduced to a spiracle.

1.2.3. Opercular gills

Opercular gills are characteristic feature of osteichthyes. Septa are usually shorter than their filament and may be virtually absent. The chief differences lie in the presence of an operculum and opercular chamber. The operculum is a bony or cartilaginous flap that commences at the hyoid arch and extends towards posteriorly covering the gill chambers on each side. Extending from the ventral edge of each operculum is supported by branchiostegal membrane with branchiostegal rays. The branchiostegal membranes of both sides are united mid ventrally beneath the gills to enclose the opercular chamber. The operculum provides a protective cover over the branchial arches and gills, in addition to the part of the dual pump mechanism is used to ventilate the gill.

2. Skin as a respiratory organ

In *Anguilla anguilla*, *Amphipnous cuchia*, *Mastocembelus pancalus*, the skin is highly vascular and serves for exchange of gases. They live in oxygen deficient stagnant water and migrate one place to another through damp vegetation. During this period, the moist skin serves as an important organ for respiration.

3. Buccopharyngeal epithelium

In some fishes (*Amphipnous*, *Boleopthalmus*) the buccopharyngeal epithelium is supplied by a large number of capillaries to make it highly vascular which performs respiratory function.

4. Pharyngeal diverticulum

In *Channa* sp. supra branchial cavities are developed in the roof of the pharynx. The supra branchial cavities possess some alveoli. The first gill arch appears to have greatly flattened and covered by a thin vascular respiratory membrane which becomes highly folded and studded with a large number of papillae or nodules forming a **labyrinthine** or **dendritic organ**. The respiratory surface extends anteriorly to the roof of the buccal cavity and the surface of the tongue. The supra branchial chamber and the entire buccopharyngeal cavity serves for aerial respiration and is filled with air during the process.

5. Alimentary canal modified for aerial respiration

In *Lepidocephalichthys guntea* the intestine is specially modified to serve for aerial breathing. The inhaled air is swallowed and forced back into the alimentary canal and is stored sometime in a special part (posterior intestine) of it. After respiratory exchange, the used air is either passed out to the exterior through the anus or is expelled through the mouth.

6. Air bladder modified as respiratory organ

The swim bladder of Notopterus has a wide pneumatic duct and acts as accessory respiratory organ. The network of blood capillaries covered by a single layer of epithelium facilities diffusion of gases between the blood and the air contained in the swim bladder.

In dipnoi the air bladder is most highly evolved acting as a lung.

7. Accessory respiratory organs

In air breathing fishes (*Clarias*, *Heteropneustes*, *Anabas*) sac-like diverticulae develop from the dorsal surface of the opercular or branchial chamber. These air chambers or **opercular lungs** lie above the gills and may contain specialized structures called labyrinthine organs or rosettes to increase the respiratory surface.

Clarias batrachus

The accessory air breathing organs of this fish consist of: supra branchial chamber, air-trees or rosettes, fans and respiratory membrane. The supra branchial chamber lies above the gills and is divided into two cup like compartments and is lined by a highly vascular respiratory membrane. Two beautiful rosettes or **air-trees** on each side are supported by 2^{nd} and 4^{th} branchial arches. The primary gill lamellae of each gill arch are fused to form a **fan** or **gill plate** consists of vascular areas.

Heteropneustes fossilis

The accessory respiratory organs are: expanded gill plates, air sac and the respiratory membrane. A pair of simple sac like structure extends posteriorly from the supra branchial chamber up to the middle of the caudal region. The **air sacs** are thin walled, long tubular structures with highly vascular walls and embedded between the myotomes of the body. The air sacs receive blood from the 4^{th} afferent branchial vessel. The respiratory membrane lining the air sac is thrown into folds and ridges and is composed of vascular areas known as **respiratory islets** which are the sites of gaseous exchange.

Anabas testudineus

In this fish the air breathing organ consists of a spacious air chamber on either side of the skull lying between the first gill arch and the hyomandibular. The **labyrinthine organ** develops from the epibranchial segment of the first gill arch and consists of 3 concentrically arranged bony plates. The 1^{st} plate is fused with the epithelium lining the air chamber while the 2^{nd} and 3^{rd} plates are much folded and highly complex, covered with vascular epithelium. It serves to increase the area for the absorption of oxygen.

Structure of a teleostean gill

Typically there are four pair of gills in teleosts, each of which consists of a larger lower limb and a shorter upper limb.

Gill rakers:

Gill rakers are present in one or two rows on the inner margin of each gill arch. The gill rakers are developed in various degrees and may be soft, thin, thread-like or hard, flat and triangular or even teeth like depending upon the food and feeding habits of the fish.

They form a sieve to filter out the water and protect the delicate gill filaments from solid particles. Each raker is lined with epithelial layer containing taste buds and mucus secreting cells. The taste buds help the fish to detect the chemical nature of the water.

Gill arch:
Each gill arch encloses an afferent and an efferent branchial vessels and nerves. It is also covered with epithelial layer containing a large number of mucous cells and taste buds. Each gill arch has one set of abductor and one set of adductor muscles which are responsible for the movement of the gill filaments during respiration. The abductor muscles are present on the outside of the gill arch connecting it with the proximal ends of the gill rays. The adductor muscles are present in the interbranchial septum.

Gill filaments or Primary lamellae:
Each gill arch bears two rows of gill filaments or primary gill lamellae towards the outside of the buccopharyngeal cavity. Among teleosts, the interbranchial septum is diversified. In some fishes the interbranchial septum between the two rows of lamellae is short so that the lamellae are free at their distal ends. However, in *Labeo bata* and *Tenualosa ilisha* the septum extends half way down the primary lamellae. Species (catla) that depend entirely on aquatic respiration have a large number of long gill filaments, but those (magur, singhi, koi, lata) have air breathing organs, the filaments are fewer in number and shorter in length. The shape, size and number of the primary lamellae vary in fishes with diverse habits.

The primary gill lamellae are supported by gill rays which are partly bony and partly cartilaginous and are connected with the gill arch. These lamellae are covered by an epithelium, consists of mucous secreting cells and chloride cells. Taste buds are also present which serve to detect the nature of water.

The **chloride cells** occur mainly on the proximal end of the lamellae as well as the filament epithelium. These cells are more abundant in marine teleosts than in freshwater ones. The chloride cells are rich in smooth endoplasmic reticulum, mitochondria as well as in Golgi bodies. Among freshwater teleosts the chloride cells are characterized by uptake of Na^+ and Cl^- and in salt water teleosts they are responsible for secretion (excretion) of these ions.

Secondary lamellae:
Each primary lamella bears a large number of secondary lamellae on both of its sides. These flat, leaf like structures are the main seats of gaseous exchange. Each secondary lamella consists of a central vascular core composed of pillar cells covered by basement membrane and an outer epithelium.

The **pillar cells** are characteristic structures of the teleost gills. Pillar cells appear to perform the dual function of protection against collapse of the vascular spaces and regulation of the pattern of blood flow through the secondary lamellae.

Types of gills based on the structure

Based on structure 4 types of gills are recognized in the fishes

1. Holobranch (Holo = entire; branch = gill)

A single gill bar with its anterior and posterior faces of respiratory filament

2. Hemibranch (Hemi = half; branch = gill)

A gill bar bears filament only one surface.

3. Pseudobranch (Pseudo = false; branch = gill)

Pseudobranch is modified form of hemibranch. The filaments on the posterior surface of the mandibular arch (facing to 1^{st} gill chamber) are often modified to serve a non-respiratory function. Pseudobranch is present in *Catla catla* and absent in *Wallago attu*, *Notopterus*, *Channa*. The pseudobranch may also be useful in the filling of gas bladder and in the regulation of intraocular pressure.

4. Lophobranch

A peculiar gill is observed in sea horses and pipe fishes, where the gill filaments become reduce to form a rosette like tufts. The tufts are small and attached to the greatly reduced gill arches.

Function of gill and counter current exchange

Blood vascular system of a teleost gill

Generally, only one afferent and one efferent branchial vessel is present in each arch in teleosts, but in some species (*Labeo rohita*, *Anabas testudineus*) there are two efferent branchial vessels in each arch.

Each afferent branchial vessel brings oxygen deficient blood into the gill. It runs through the entire length of the gill arch and gives a number of primary afferent branches to the primary gill lamellae. Each primary afferent vessel divided into secondary vessels, one for each secondary lamella. These run across the gill rays dividing again into 2-4 tertiary branches, interconnected with each other and forming the vascular central core of the secondary lamella. Exchange of gases takes place while the blood is circulating through these channels.

The oxygenated blood is collected by the efferent lamellar arterioles which carry the blood to the primary efferent vessel.

Water is brought in close contact with the secondary lamellae through which exchange of gases take place. Functionally the gills are very efficient and utilize about 50-80% of oxygen present.

The orientation of the afferent and efferent branchial vessels are arranged in such way that the blood and the respiratory water flow in opposite directions. This is called **counter current system** in which water containing oxygen from oral to aboral side of the gill and the blood in the lamellae flows from aboral to oral side, thus providing maximum exchange of respiratory gases.

Mechanism of respiration

In water breathing fishes the most common pump is **dual pump**. As the name suggests it consists of two pumps in tandem, buccal and opercular that works in a synchronous pattern to drive water in a continuous unidirectional flow.

Bony fishes:

The steps in the pumping cycle are:

First stroke (suction phase)

1. For respiration the mouth is opened and the buccal cavity is enlarged by lateral expansion of its wall. An increase in buccal cavity creates negative water pressure in it so outside water is inhaled in following the pressure gradient.
2. When the buccal cavity is filled with water, the mouth is closed and the operculum is abducted anteriorly to increase the opercular cavity. At this time the opercular opening is kept closed due to the pressure of the external water. Pressure increases in the buccal cavity but oral valve preventing any back flow. A low pressure is thus created in the opercular cavity and water flows over the gills into it.

Second stroke (force/pressure phase)

3. The buccal and opercular cavities are reduced so as to exercise pressure on the water inside it. The oral valves prevent the water from going out of the mouth. The pressure in the buccal cavity is greater than in the opercular cavity, maintain a vigorous respiratory flow across the gill. The opercula after reaching the maximum abduction are quickly brought towards the body and the water leave though it.
4. The cycle ends with the buccal pump switching back to suction pump action. The next cycle soon flows.

The timing of the suction and force phase together with pressure differentials between them results in the continuous directional flow of new water across the gills.

Elasmobranches:

In shark ventilation is based on a dual pump mechanism that creates alternating negative and positive pressure to draw the water in and then drive it across the gill curtain. Pressures recorded on either side of the gill curtain within the buccal and parabranchial compartments reveal the efficiency of this dual pump. The pressure rises and falls in each cavity. The pressure is always relatively lower in the parabranchial cavity, located lateral to the gills than in the buccal cavity, located medial to the gills.

In addition to bringing new pulses of water into the mouth, the dual pump mechanism of the shark also maintains a nearly constant pressure difference between buccal and parabranchial compartments. As a result, the pressure oscillations of the dual pump are converted into a smoother, almost continuous unidirectional irrigation of the gills.

Blood coursing within the capillaries of the secondary lamellae set up a countercurrent pattern promoting efficient gas exchange.

Ram ventilation

Many active fast swimming fishes such as *Tuna* and some sharks swim with their mouth open and consequently force water over their gills. This is called Ram ventilation. It suggests that the increase energy requirements of swimming are less than the requirement of mouth and opercular pumping in order to ensure the delivery of water and oxygen to the gills.

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"It is good luck to any person to be on the good side of the man that knows fish"-Izaak Walton

RESPIRATION IN BIRD

Vertebrate lungs are designed for air-breathing. Lungs are elastic bag like structure that lie within the body. Their volume expands when air is inhaled and decreases when air is edxhaled. Embryologically, lungs arise as endodermal out pocketing from the gut. In most tetrapodes the lung is usually paired. They lie ventral to the digestive tract and connected to the outside and environment through trachea. The entrance of the trachea is provided by the glottis which is guarded by tiny sets of muscle that open and close it. Usually the trachea divided into two bronchi one to each lung. A typical condition in some species each bronchus branches into successive smaller bronchioles that eventually supply air to the respiratory surfaces within the lung. The trachea, bronchi and bronchioles can hold a significant volume of air. Although exhalation faces most of the spent air from the lungs, some remain in the respiratory passage way; upon inhalation this spent air is drawn back into the lungs before fresh air from outside reaches the lungs to mix with the used air. This volume of used air with in the respiratory passage way is called the dead space. The total volume inhaled a single breath is referred to as the tidal volume.

Respiratory organ in bird

Birds can breathe through the mouth or the nostrils (nares). Air entering these openings (during inspiration) passes through the pharynx & then into the trachea. The **lungs** of birds are mostly spongy organ with little elasticity differ from those of other vertebrates in that they do not store air. Lungs lie in the pleural cavity which are separated from the peritoneal or abdominal coelom by an oblique septum. The dorsal surface of the lung adhere firmly to the ribs and thoracic vertebrae and it has no peritoneal covering. But the ventral surface is covered by a special, fibrous peritoneal membranes-pleura.

Trachea

Trachea is elongated tube begins from glottis and runs along the neck region along the ventral side of the oesophagous. The trachea is composed of bony tracheal rings.

Larynx

Near the commencement the trachea is enlarged into a chambered called the larynx.

Syrinx

The trachea bifurcates (or splits) into two primary bronchi at the syrinx. The syrinx is unique to birds and serves as 'voicebox' (in mammals, sounds are produced in the larynx). It is formed by the dilation of the last three or four tracheal rings and first bony ring of each bronchus.

The mucous membrane of the syrinx consists of a pad like thickening and is provided with several muscles and membranes. A bar of cartilage called pessulus is present at the junction of two bronchi. It extends dorsoventrally inside the tympanum and holds a small fold of mucous membrane called semilunar membrane. The sound is produced by the vibration of the semilunar membrane while the pitch of the sound is controlled by the action of the syrigeal musculature. The syringeal musculature includes a pair of intrinsic syrigeal muscles and a pair of sternotracheal muscle.

Bronchi

The trachea expands into a syrinx and then divides into bronchi one for each lung.

Mesobrochi

The trachea is divided into two primary bronchus termed as mesobronchi, that do not enter the lung but extend posteriorly to reach the posterior air sacs.

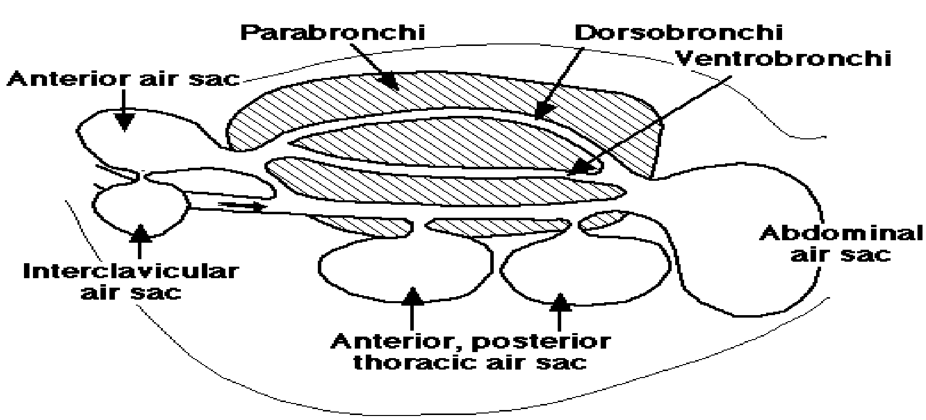
Secondary bronchi

Branching off from the mesobronchi are smaller tubes called latero, dorso and ventrobronchi, lead into the smaller parabronchi.

Parabronchi

Parabronchi can be several millimeters long and 0.5 - 2.0 mm in diameter (depending on the size of the bird) and their walls contain hundreds of tiny, branching and anastomosing 'air capillaries' surrounded by a profuse network of blood capillaries. Blood capillaries lining of air capillaries that constitutes the respiratory epithelium.

Within these 'air capillaries' that the exchange of gases (oxygen and carbon dioxide) between the lungs & the blood occurs. The parabronchi then lead into larger dorsobronchi which, in turn, lead back into mesobronchi.

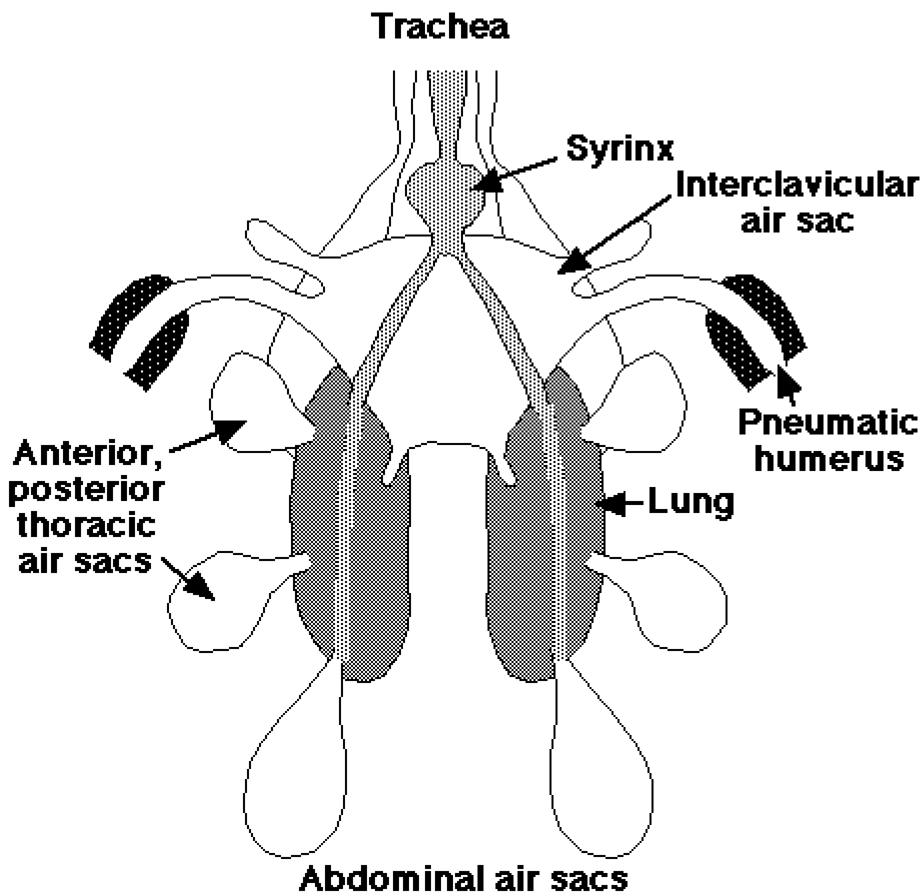


Air sacs

Most birds have 9 air sacs:

- one interclavicular sac
- two cervical sacs
- two anterior thoracic sacs
- two posterior thoracic sacs
- two abdominal sacs

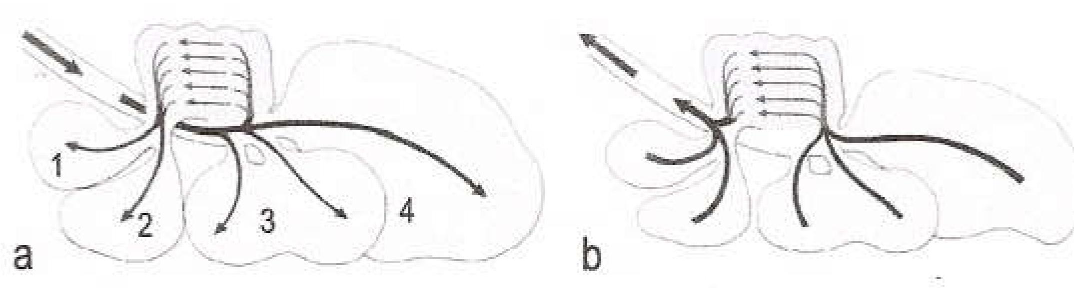
Functionally, these 9 air sacs can be divided into anterior sacs (interclavicular, cervicals, & anterior thoracics) & posterior sacs (posterior thoracics & abdominals). Air sacs have very thin walls with few blood vessels. So, they do not play a direct role in gas exchange.



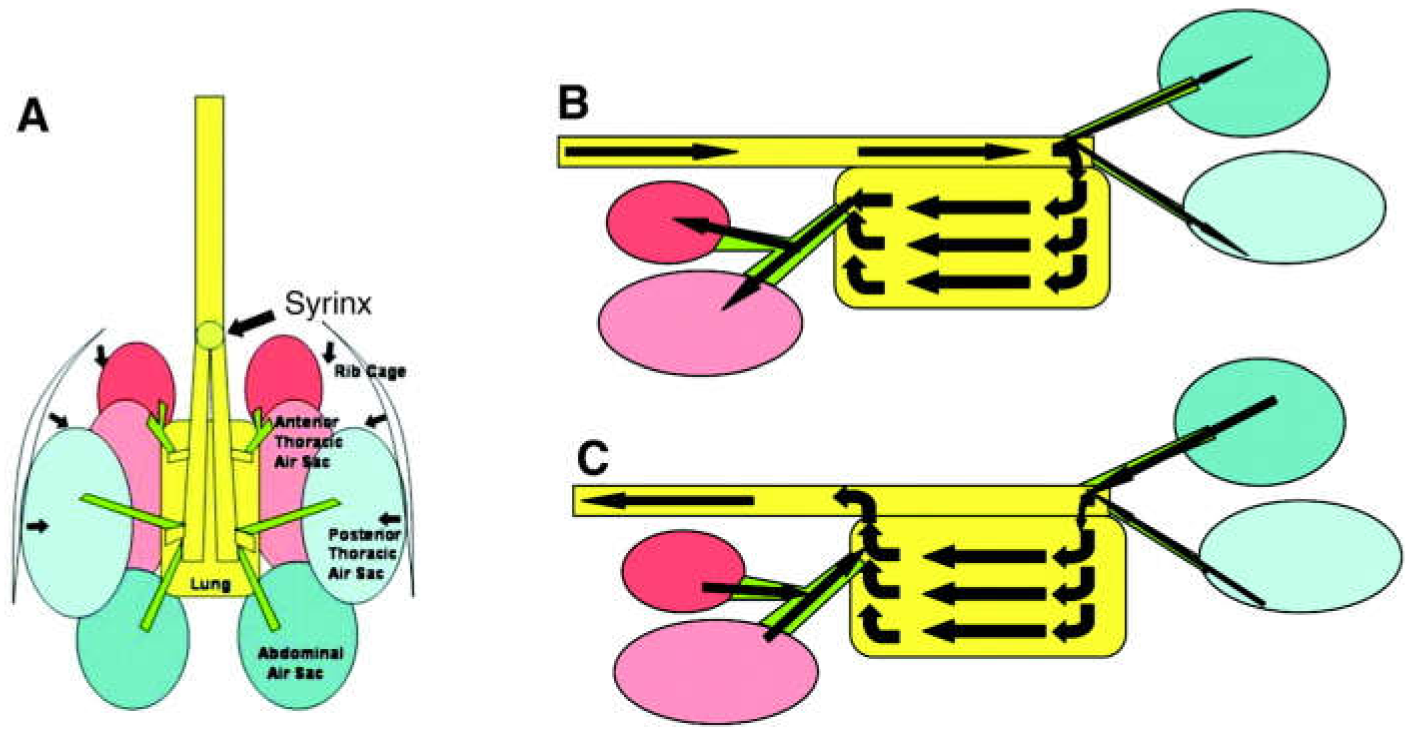
Machanism of respiration

The avian respiratory system delivers oxygen from the air to the tissues and also removes carbon dioxide. In addition, the respiratory system plays an important role in thermoregulation (maintaining normal body temperature). The avian respiratory system is different from that of other vertebrates, with birds having relatively small lungs plus nine air sacs that play an important role in respiration (but are not directly involved in the exchange of gases).

The air sacs permit a unidirectional flow of air through the lungs. Unidirectional flow means that air moving through bird lungs is largely 'fresh' air & has a higher oxygen content. In contrast, air flow is 'bidirectional' in mammals, moving back & forth into & out of the lungs. As a result, air coming into a mammal's lungs is mixed with 'old' air (air that has been in the lungs for a while) & this 'mixed air' has less oxygen. So, in bird lungs, more oxygen is available to diffuse into the blood



Air flow through the avian respiratory system during inspiration (a) and expiration (b). 1-interclavicular air sac, 2-cranial thoracic air sac, 3-caudal thoracic air sac, 4-abdominal airs ac



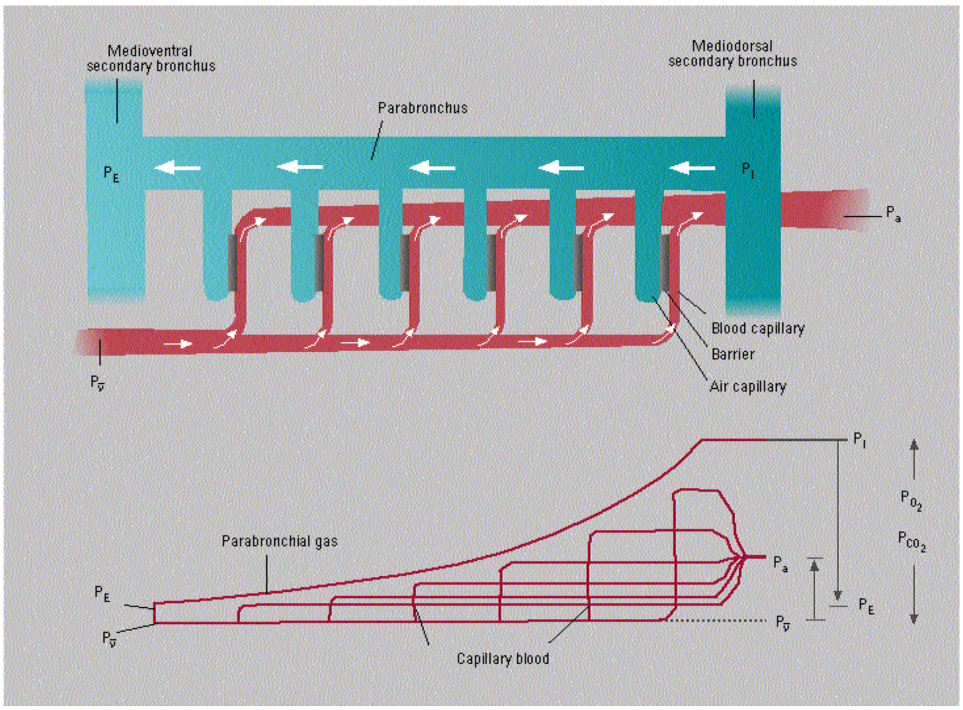
A schematic of the avian respiratory system, illustrating the major air sacs and their connections to the lung. (A) The lateral and dorsal direction of motion of the rib cage during exhalation is indicated by arrows. (B) The direction of airflow during inspiration. (C) The direction of flow during expiration.

During inhalation, air moves into the posterior air sacs and, simultaneously, into the lungs and through the parabronchi and into the anterior air sacs.

During exhalation, air moves out of the posterior air sacs into and through the parabronchi and, simultaneously, out of the anterior air sacs and out of the body via the trachea.

During inhalation, all air sacs expand as inhaled air enters the posterior air sacs and lungs and, simultaneously, air moves out of the lungs and into the anterior air sacs.

During exhalation, the air sacs diminish in volume as air moves (1) from the posterior air sacs through the lungs and (2) from the anterior air sacs and out of the body via the trachea.



Top: Schematic of air flow (large arrows) and blood flow (small arrows) patterns constituting the cross-current gas-exchange mechanism operating in the avian lung. Note the serial arrangement of blood capillaries running from the periphery to the lumen of the parabronchus and the air capillaries radially departing from the parabronchial lumen. **Bottom:** Pressure profiles of O_2 and CO_2 from initial parabronchial (P_I) to end-parabronchial values (P_E); and in blood capillaries from mixed venous (Pv) to arterial blood (Pa). The $P_{O2}$of arterial blood is derived from a mixture of all serial air-blood capillary units and exceeds that of P_E. In mammals, the PaO2 cannot exceed that of end-expiratory gas (i.e., PE).

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"Don't believe in luck, believe in hard work"